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Photonuclear Data - Abstract Sheets 1955 - 1982 Volume VIII (Scandium - Manganese)

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
National Measurement Laboratory
Center for Radiation Research
Gaithersburg, MD 20899

May 1985



U.S. DEPARTMENT OF COMMERCE

BUREAU OF STANDARDS

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1985

NBSIR 83-2742

**PHOTONUCLEAR DATA - ABSTRACT SHEETS
1955 - 1982
VOLUME VIII (SCANDIUM - MANGANESE)**

E. G. Fuller, Henry Gerstenberg

U.S. DEPARTMENT OF COMMERCE
National Bureau of Standards
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**U.S. DEPARTMENT OF COMMERCE, Malcolm Baldrige, *Secretary*
NATIONAL BUREAU OF STANDARDS, Ernest Ambler, *Director***

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Photonuclear Data-Abstract Sheets
1955-1982

I. Introduction

As used in connection with this collection of data-abstract sheets, the term photonuclear data is taken to mean any data leading to information on the electromagnetic matrix element between the ground state and excited states of a given nuclide. The most common types of reactions included in this compilation are: (e,e') , (γ,γ) , (γ,γ') , (γ,n) , (γ,p) , etc. as well as ground-state particle capture reactions, e.g. (α,γ_0) . Two reactions which fit the matrix element criterion are not included in the compilation because of their rather special nature. These are heavy particle Coulomb excitation and the thermal neutron capture reaction (n,γ_0) . While the energy region of particular interest extends from 0 to 150 MeV, papers are indexed which report measurements in the region from 150 MeV to 4 GeV. Most of the experiments listed are concerned with the excitation energy range from 8 to 30 MeV, the region of the photonuclear giant resonance.

The hierarchical grouping of the photonuclear data-abstract sheets within the file is by: 1. Target Element, 2. Target Isotope, and 3. by the Bibliographic Reference Code assigned to the paper from which the data on the sheet were abstracted. In this file, colored pages are used to mark the beginning and end of the sheets for each chemical element. A brief historical sketch of the element is given on the divider sheet marking the start of each section; the information for this sketch was derived from references such as the Encyclopaedia Britannica. In those cases where the sheets for a given element make up a major part of a volume, colored pages are also used to delineate sections pertaining to the individual isotopes of the element. Each of the sections of the file, as delineated by two colored divider sheets, represents a 27 year history of the study of electromagnetic interactions in either a specific nuclide or a specific element.

The data-abstract sheets are filed under the element and/or isotope in which the ground-state electromagnetic transition takes place. For example, the abstract sheet for a total neutron yield measurement for a naturally occurring copper sample would appear in the elemental section of the copper file. On the other hand, a measurement of the ^{62}Cu 9.73 minute positron activity produced in the same sample by photons with energies below the three-neutron separation energy for ^{65}Cu (28.68 MeV) would be filed with the sheets for ^{63}Cu . Similarly a measurement of the ground-state neutron capture cross section in ^{12}C would be filed under ^{13}C while the corresponding ground-state alpha-particle capture cross section would be filed under ^{16}O .

At the end of this volume there is a master list of the abbreviations that have been used in the index section of the abstract sheets. The listings are those used in the final published index, Photonuclear Data Index, 1973-1981, NBSIR 82-2543, issued in August 1982 by the U. S. Department of Commerce, National Bureau of Standards, Washington, DC 20234. In some cases two notations are entered for the same quantity. The second entry is the abbreviation that was used in one or more of the earlier published editions of the index.

SCANDIUM
Z=21

Scandium is a metallic element found mainly in rare ores of Scandinavia from which it derived its name. The oxide, scandia, was discovered by L. F. Nilson in 1879. The event was of great scientific interest because this and other compounds of scandium had properties as predicted by Mendel'eyev in 1869 for the derivatives of a hypothetical element ekaboron. This element was needed to fill a gap in the periodical classification of the chemical elements.

Sc
A=41

Elem. Sym.	A	Z
Sc	41	21
Ref. No.		JHH
61 Bu 1		

Method Van de Graaff; NaI for prompt γ 's; thin "pilot-B" plastic scintillator for $\text{Sc}^{41} \rightarrow \text{Ca}^{41}$ positrons

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Ca}^{40}(p,\gamma)$	650 \pm 5kev	1.723 \pm 0.011	< 5 kev	0.02 ev-barns		$E_\gamma = 1.71 \pm 0.03$ MeV
	1550 \pm 15? kev	2.590 \pm 0.018	< 10? kev	0.03? ev-barns		
	1630 \pm 15? kev	2.669 \pm 0.018?	< 10? kev	0.03? ev-barns		
	1850 \pm 10 kev	2.883 \pm 0.014	< 10 kev	0.3 ev-barns		$E_{\gamma_0} = 2.89 \pm 0.02$ MeV. Assuming 2.89 MeV γ is to ground state, Q-value for reaction $\text{Ca}^{40}(p,\gamma)\text{Sc}^{41}$ is calculated to be 1.09 ± 0.02 MeV. Question marks indicate doubtful assignment as Ca^{40} resonances. Integrated cross sections $\int \sigma dE$ refer to (p, γ) rather than (γ ,p).

ELEM. SYM.	A	Z
Sc	41	21
REF. NO.		
77 Ko 4		hmg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$P, G	LFT	3,5	D	1,5	SCD-D		DST
		(2.883, 5.037)		(1.84, 4.05)			

Proton and γ -ray decay widths for the $7/2^+$ resonance at 2883 keV excitation in ^{41}Sc have been deduced from measurements of Γ_γ/Γ and the (p, γ) resonance strength. Our results are $\Gamma_\gamma = 0.058 \pm 0.007$ eV and $\Gamma = 0.090 \pm 0.011$ eV. Angular distributions measured for the 5037 ($9/2^+$)—2883 keV and 2883—0 ($7/2^+$) keV transitions confirm the $J = 7/2$ assignment for the 2883-keV level. The linear polarization was measured for the 2883—0 keV transition and confirms the positive parity assignment. In addition, the (p, γ) strength for the 5037-keV level was measured, and our strength results for both resonances are lower than those of Youngblood, Wildenthal, and Class by a factor of 1.4.

Pol scat G's, 2.8MeV

TABLE 2. Summary of angular distribution results and comparisons with other work.

E_p (keV)	E_i (keV)	E_f (keV)	E_γ^a (keV)	$J_i^\pi \rightarrow J_f^\pi$	Normalized Legendre coefficients		Mixing ratio δ	Branching ratio (%)	Ref.
					a_2	a_4			
4051.2 \pm 1.4	5036.9 (R)	0	5036.9	$\frac{9}{2}^+ \rightarrow \frac{7}{2}^+$	-0.265 ± 0.039	-0.031 ± 0.039	$-0.017^{+0.015}_{-0.008}$	72 ± 2	b
	5036.9 (R)	2883.1	2153.9	$\frac{9}{2}^+ \rightarrow \frac{7}{2}^+$	-0.270 ± 0.042	-0.024 ± 0.043	$-0.017^{+0.021}_{-0.022}$	26 ± 2	b
	5036.9 (R)	3358.1	1678.8	$\frac{9}{2}^+ \rightarrow (\frac{11}{2}^+)$	-0.169 ± 0.179	0.066 ± 0.194		2.7 ± 0.5	b
	2853.1	0	2883.1	$\frac{7}{2}^+ \rightarrow \frac{7}{2}^+$	0.467 ± 0.054	0.017 ± 0.064	$-0.035^{+0.072}_{-0.036}$	100	b, c
	5036 (R)	0	5036	$\frac{9}{2}^+ \rightarrow \frac{7}{2}^+$	-0.215 ± 0.021	-0.069 ± 0.025	$(-)0.035$		d
1643.1 \pm 1.0	2853.1 (R)	0	2853.1	$\frac{7}{2}^+ \rightarrow \frac{7}{2}^+$	0.517 ± 0.034	-0.060 ± 0.046	$-0.052^{+0.043}_{-0.059}$	100	b
	2879 (R)	0	2879	$\frac{7}{2}^+ \rightarrow \frac{7}{2}^+$	0.507 ± 0.023	-0.025 ± 0.031	$(-)0.035$		d
	2882.1 (R)	0	2882.1	$\frac{7}{2}^+ \rightarrow \frac{7}{2}^+$	0.498 ± 0.034	0.008 ± 0.040	$-0.26^{+0.41}_{-0.33}$	100	e

^a Results from the present work have ± 0.5 keV uncertainty.

^b Present work.

^c Primary mixing ratio was taken to be -0.017 .

^d See Ref. 2.

^e See Ref. 16.

² D.H. Youngblood, B.H. Wildenthal, and C.M. Class,
Phys. Rev. 169, 859 (1968)

¹⁶ B. Rabin, Ph.D. thesis, Strasbourg-1 University,
1973 (unpublished)

Sc
A=43

Sc
A=43

Sc
A=43

REF.

A. E. Vlieks, C. W. Cheng and J. D. King
Nucl. Phys. **A309**, 506 (1978)

ELEM. SYM.

A

Z

Sc

43

21

METHOD

REF. NO.

78 V1 2

rs

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	ABX	6- 11	D	1- 6	NAI-D		4pI

Abstract: The cross section for the $^{42}\text{Ca}(p,\gamma)^{43}\text{Sc}$ reaction has been measured over the lab energy range from 0.7 to 5.5 MeV using a positron spectrometer to measure the annihilation radiation from the decay of 3.9 h ^{43}Sc . Stellar reaction rates $N_A\langle\sigma v\rangle$ have been calculated from the experimental cross section curve for a series of three temperatures of interest for explosive oxygen and silicon burning in stars. The calculated rates are compared with the theoretical predictions of Woosley *et al.* and found to be in agreement within the experimental errors and the quoted validity of the theoretical calculation.

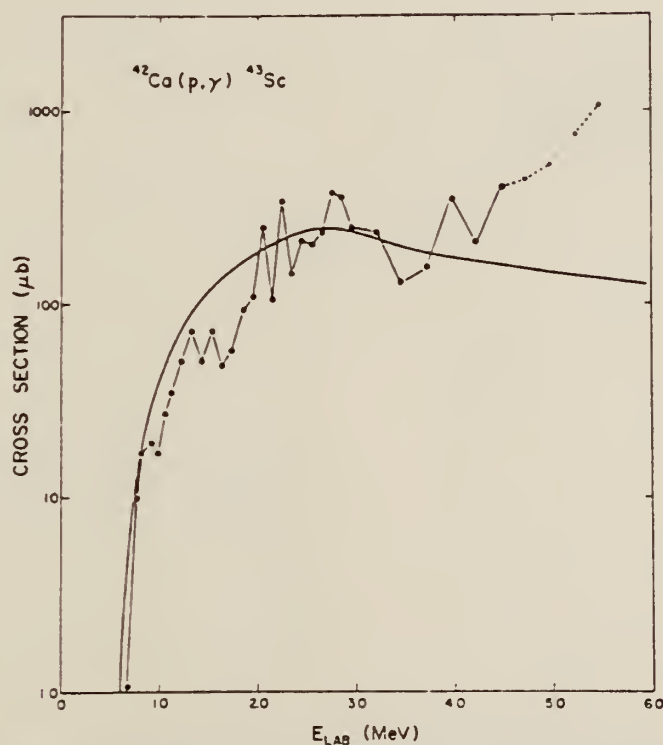


Fig. 1 The cross section for the $^{42}\text{Ca}(p,\gamma)^{43}\text{Sc}$ reaction. The solid curve is the calculated cross section from ref. ⁴) as estimated from a graph. The magnitude of the cross section is somewhat uncertain above 4.5 MeV due to contributions to the observed yield from the $^{42}\text{Ca}(p,n)$ reaction.

⁴ S. E. Woosley, W. A. Fowler, J. A. Holmes and B. A. Zimmerman,
Caltech preprint OAP422 (1975)

Sc
A=45

Sc
A=45

Sc
A=45

METHOD

Bremsstrahlung from Linac

REF. NO.

66 Ta 1

JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	RLY	THR - 48	C	24-48	ACT-I		4PI

Level density $\rho(J) = \rho(0)(2J + 1) \exp [-(J + \frac{1}{2})^2 / 2\sigma^2]$
 Measured relative yield to g.s. and .27 MeV isomer.

TABLE I. Isomer ratios for ^{44}Sc , ground-state yield/total yield $g/(g+m)$.

	Reaction		
	$^{44}\text{Sc}(\gamma, n)$	$^{46}\text{Ti}(\gamma, np)$	$^{44}\text{Sc}(n, 2n)$
Bremsstrahlung endpoint energy (MeV)			
24	0.86 ± 0.02		
36	0.84 ± 0.02		
48	0.84 ± 0.03	> 0.98	
X-radiation energy range (MeV)			
Threshold-24	0.86 ± 0.02		
24-36	0.79 ± 0.13		
36-48	0.84 ± 0.40		
Neutron energy 13.9 MeV			
From measurement of the 1.16-MeV γ line			0.581 ± 0.025
From measurement of the annihilation radiation			0.586 ± 0.025

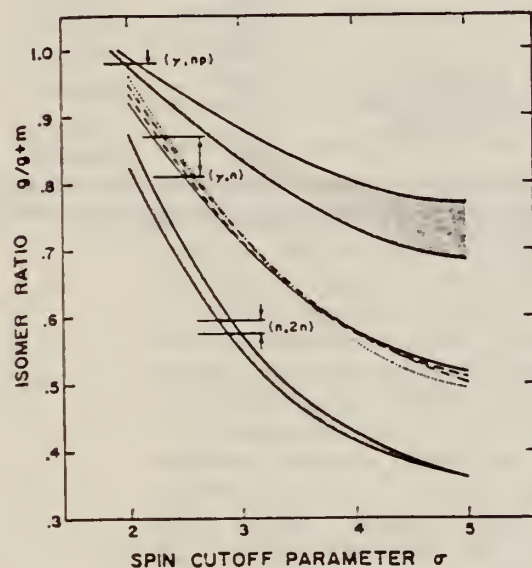


FIG. 6. Calculated isomer ratios versus spin cutoff parameter σ . The top shaded area shows typical calculated results as a function of σ for the (γ, np) reaction. The horizontal line at $g/(g+m) = 0.98$ is the experimental value. The bottom area shows results obtained for the $(n, 2n)$ reaction with the two horizontal lines indicating the experimental result. The middle set of curves are results for the (γ, n) reaction. Each line corresponds to a different assumption which is given in the text.

METHOD

Betatron

REF. NO.

66 Wa 1

JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	RLY	THR-300	C	50-300	ACT-1		4PI

Measured isomeric yield ratios.

TABLE II. Summary of the results for the photoproduction of the Sc^{44} isomers (spins 2 and 6).

Target isotope and spin	Bremsstrahlung energy (MeV)	Fraction of yield to high-spin isomer
Sc^{44} ($I = \frac{1}{2}$)	50	0.21 ± 0.04
	75	0.21 ± 0.03
	175	0.20 ± 0.02
	223	0.18 ± 0.01
	264	0.17 ± 0.02
	300	0.21 ± 0.02
$\text{Fe}^{54,56}$ ($I = 0$) ^a	250	0.38 ± 0.02
Mn^{55} ($I = \frac{1}{2}$)	225	0.42 ± 0.04
	300	0.39 ± 0.02

^a It is assumed that most of the yield is due to reactions involving the two lightest isotopes present in natural iron (Fe^{54} and Fe^{56}).

ELEM. SYM.	A	Z
Sc	45	21
REF. NO.	67 Be 8	EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	11-48	C	48	ACT-I		4PI
G,2N	ABY	21-48	C	48	ACT-I		4PI
G,2P	ABY	19-48	C	48	ACT-I		4PI

Photonuclear Reactions with Emission of Several Nucleons

H. Bernatowicz and H. A. Medicus

Rensselaer Polytechnic Institute, Troy, N.Y., U.S.A.

Photonuclear reactions were induced on scandium and vanadium by bremsstrahlung at the Rensselaer Electron Linac. The activity of the residual nuclei was measured. The approximate energy dependence of the photonuclear reactions was either estimated by rough application of the photon difference method or calculated. This permitted determination of integrated cross sections by comparison with the activity of a beam monitor with known cross section.

Competing reactions, especially those involving emission of more than one particle, are a sensitive test of evaporation theory. Detailed calculations were therefore performed using various level density formulas. The Fermi gas formula, $\rho \sim s^{2\sqrt{aU}/U^{5/4}}$, (where $s = A/8 \text{ Mev}^{-1}$ and U is the excitation energy minus pairing energy), Weisskopf's formula, $\rho \sim s^{2\sqrt{aU}}$, and the constant temperature formula $\rho \sim e^{(E - E_0)/T}$ were tried. Corrections to the Fermi gas formula for shell effects have been made by Newton¹ and by Gilbert and Cameron². Gilbert and Cameron also proposed a composite formula which joins the Fermi gas expression smoothly to a constant temperature formula below 8 Mev. The calculated integrated cross sections using these formulas were found to differ by as much as several orders of magnitude. The composite formula with Gilbert and Cameron's parameters gave the best overall agreement with our experimental data. The composite formula with optical model inverse cross sections³ and giant resonance data from Fultz, et al.,⁴ are given in the table. Results using the constant temperature, Fermi gas, and Fermi gas formula with shell corrections by Newton have been included in one case. Integrated cross sections are in Mev-mb.

Target	End Point	Results	(γ,n)	($\gamma,2n$)	($\gamma,3n$)	($\gamma,2p$)	(γ,α)	($\gamma,\alpha n$)
⁴⁵ Sc	48 MeV	Composite	310	78		2.0×10^{-1}		
		Experiment	430 ± 70	68 ± 12		3.0 ± 0.8		
⁵¹ V	37 MeV	Composite		140	1.4	6.3×10^{-1}	3.1	1.6
		Constant T		99	2.0	3.8	1.3	0.37
		Fermi Gas		97	1.3	3.5×10^{-2}	1.0	30
		Newton		101	2.1	3.2×10^{-3}	0.44	8.6
		Experiment		124 ± 35	2.5 ± 0.5	$(2.4 \pm 0.5) \times 10^{-1}$	7.1 ± 1.5	$3.0 \pm 2.$
⁵¹ V	29 MeV	Composite		106		4.9×10^{-2}	2.9	
		Experiment		115 ± 30		$(1.7 \pm 0.3) \times 10^{-2}$	6.8 ± 1.4	
⁵¹ V	25 MeV	Composite		60		3.0×10^{-4}	2.4	
		Experiment		62 ± 12		$(2.6 \pm 0.3) \times 10^{-4}$	4.9 ± 1.2	

When the parameters of Newton were used in a composite level density formula agreement improved but remained significantly poorer than obtained with Gilbert and Cameron's parameters. The large disparity found in the ⁴⁵Sc($\gamma,2p$) result would be eliminated by a 15 percent increase in the level density parameter of ⁴⁴Ca which has a closed proton shell. Our work indicates that this type of experiment can be of significant value in the study of nuclear level densities.

- References: 1. Newton, T. D. Can. J. Phys. 34, 804 (1956).
 2. Gilbert, A. and Cameron, A. G. W. Can. J. Phys. 43, 1449 (1965).
 3. Mäldner, H. and Lindner, A. Z. Physik 180, 362 (1964).
 4. Fultz, S. C., Bramblett, R. L., Caldwell, J. T., Hansen, N. E., and Jupiter, C. P. Phys. Rev. 128, 2345 (1962).

REF.

R. G. Arnold, E. C. Booth, and W. J. Alston, III
Phys. Rev. C7, 1490 (1973)

ELEM. SYM.

A

Z

Sc

45

21

METHOD

REF. NO.

73 Ar 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	0- 3	G	0- 3	SCD-D		125

13 LEVELS

Absolute values come from normalizing to know total widths.
W is angular distribution factor to correct for difference
in unknown and standard distribution. Assumed = 1 to get
 Γ_0 values.

TABLE II. M1 strengths and mixing ratios in ^{45}Sc .

Level energy (keV)	$B(E2)^\dagger$ Previous work ($e^2\text{fm}^4$)	$g\Gamma_0(E2)^\ast$ (meV)	$g\Gamma_0(M1+E2)$ This work (meV)	δ^2 Deduced	$g\Gamma_0(M1)$ Deduced (meV)	$\Gamma_0(M1)/\Gamma_W(M1)^\flat$
720	72(10) ^c	0.0113(16)	1.58(16)	0.0072(13)	1.57(16)	0.27
1237	154(21) ^c	0.36(5)	0.38(2)	>4.0	<0.08	...
1663	69(21) ^d	0.71(21)	3.87(41)	0.22(7)	3.16(45)	0.033 ^e

^a Derived from column 2.^b Transition strength in W.u.^c Average of values listed in Table 1 of Ref. 3 plus results from Ref. 2 with the results of M. D. Goldberg and B. W. Hooton, Nucl. Phys. A132, 369 (1969) omitted from the average.^d R. J. Peterson and D. M. Periman, Nucl. Phys. A117, 185 (1968). Estimated 30% uncertainty not explicitly given by the authors.^e Assuming $g=1.0$.¹ M. B. Lewis, Nucl. Data B4(Nos. 3,4) 237 (1970).² P. Blasi et al., Nuovo Cimento 68, 49 (1970).³ D. A. Eastham et al., Nucl. Phys. A146, 112 (1970).

(over)

TABLE I. ^{45}Sc levels and results.

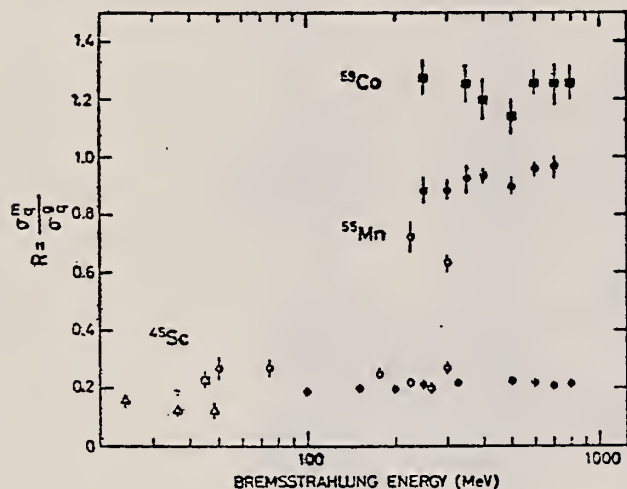
Level energy ^a (keV)	$J\pi^a$	E_γ This work (keV)	Γ_0/Γ or Γ_1/Γ	$g\bar{W}\Gamma_0\Gamma_0/\Gamma$ This work (meV)	Γ_0 Deduced (meV)
g.s.	$\frac{1}{2}^-$...			
12.4(2)	$\frac{3}{2}^+$	...	1.0 ^b	c	...
376.7(6) ^d	$\frac{1}{2}^-$	...	0.92 ^d	c	...
543.1(6) ^d	$\frac{3}{2}^+$	531(2) ^e 543(2)	0.58(1) ^{d,e} 0.42(1) ^d	0.019(4) ^e 0.011(3)	... 0.039(8)
720.5(5) ^d	$\frac{1}{2}^-$	720(1)	1.0 ^b	1.58(16)	2.11(21)
939.1(9) ^d	$\frac{3}{2}^+$	...	0.0	...	...
974.3(7) ^d	$\frac{7}{2}^+$	962(2) ^e 974(2)	0.32(1) ^{d,e} 0.58(1) ^d	0.062(9) ^e 0.08(1)	... 0.17(3)
1068.4(10) ^d	$\frac{1}{2}^-$	...	0.0 ^d	...	...
1237.4(9) ^d	$(\frac{1}{2})^-^f$	1237(2)	1.0 ^d	0.38(2)	0.58(3)
1409.0(10) ^d	$(\frac{3}{2})^-^d$	1409(1)	0.91(4) ^d	1.36(11)	1.87(16)
1433.5(10) ^d	$(\frac{3}{2})^+^d$	...	0.10(2) ^d	<0.2	...
1474(3)	...	...	...	<0.2	...
1557(3)	$(\frac{1}{2}, \frac{3}{2})^-$	...	0.0 ^b	<0.2	...
1661.8(7) ^d	$(\frac{3}{2}, \frac{5}{2})^-^d$	1663(2)	0.83(4) ^d	3.2(3)	3.9(4) g ⁻¹
1799(5)	...	1798(2)	0.23(3) §	0.22(5)	0.94(21) g ⁻¹
1897(5)	...	...	1.0 §	<1.0	...
1936(5)	...	...	...	c	...
2031.0(10) ^d	$(\frac{1}{2})^+^d$	...	...	<0.5	...
2095(5)	...	2093(2)	0.78(12) §	47(2)	60(9) g ⁻¹
2106(5)	...	...	...	<0.5	...
2223(5)	...	...	...	<0.5	...
2291(5)	...	2291(3)	...	1.28(8)	...
2303(5)	...	...	0.0 §	<0.5	...
2341(5)	$(\frac{3}{2})^-^f$	2341(2)	...	16(1)	...
2351(5)	...	...	0.02 ^{b,h}	<0.5	...
2531(5)	...	...	0.0	<2	...
2562(5)	...	...	...	<2	...
2590(5)	...	2592(2)	0.64(9) §	8.9(5)	14(2) g ⁻¹

^a Except where noted Ref. 1.^b Reference 1.^c No data taken for these levels.^d Reference 2.^e Branch to the first excited state. Transition strength in column 5 is $g\bar{W}\Gamma_0\Gamma_1/\Gamma$.^f See discussion in the text.[§] Private communication from J. C. Manthuruthil of preliminary results related to work reported in Ref. 4. He estimates 10 to 20% uncertainty in branching ratios.^h Manthuruthil (see footnote d) reports a level at 2355 ± 2 keV with $\Gamma_0/\Gamma = 0.63$ which may be the same as the level at 2351.

ELEM. SYM.	A	Z
Sc	45	21

METHOD	REF. NO.	
	73 Er 1	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NOX	0-800	C	100-800	ACT-I		4PI

SC-44 ISOMER RATIO

Isomeric yield ratio,
 $^{44}\text{Sc}^m(6+)/^{44}\text{Sc}^g(2+)$,
 versus bremsstrahlung
 end point energy.

●, ■ this work, Δ ref 1,
 ○ ref 2, □ ref 3.

- ¹J.R. Tatarczuk and H.A. Medicus, Phys. Rev. 143 (1966) 818.
- ²W.B. Walters and J.P. Hummel, Phys. Rev. 150 (1966) 867.
- ³R. Völpe, Nucl. Phys. A182 (1972) 311.

METHOD

REF. NO.

73 Sa 5

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	10- 25	C	10- 25	BF3-I		4PI

589

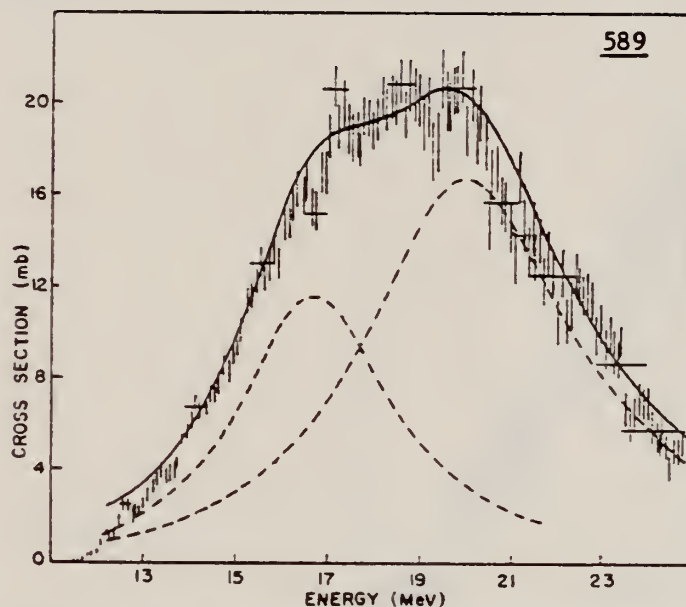


Fig. 1. The total photoneutron cross section $\sigma(\gamma, n) + \sigma(\gamma, np) + \sigma(\gamma, 2n)$ for ^{43}Sc . The horizontal bars indicate the resolution width. The smooth curve represents the Danos model fit which is the sum of the two dashed Lorentz curves.

Yields corrected by using statistical model with 20% direct reactions assumed.

TABLE I
Integrated cross section and moments from threshold to 25 MeV

σ_0 (mb · MeV)	σ_{-1} (mb)	σ_{-2} (mb · MeV ⁻¹)
158 ± 24	8.4 ± 1.3	0.46 ± 0.07

$$\sigma_n = \int_{\text{thres}}^{25 \text{ MeV}} \sigma E^{-n} dE.$$

REF.

R. H. Sambell and B. M. Spicer
PICNS-73, Vol. I, p. 541 Asilomar

ELEM. SYM.

A

Z

Sc

45

21

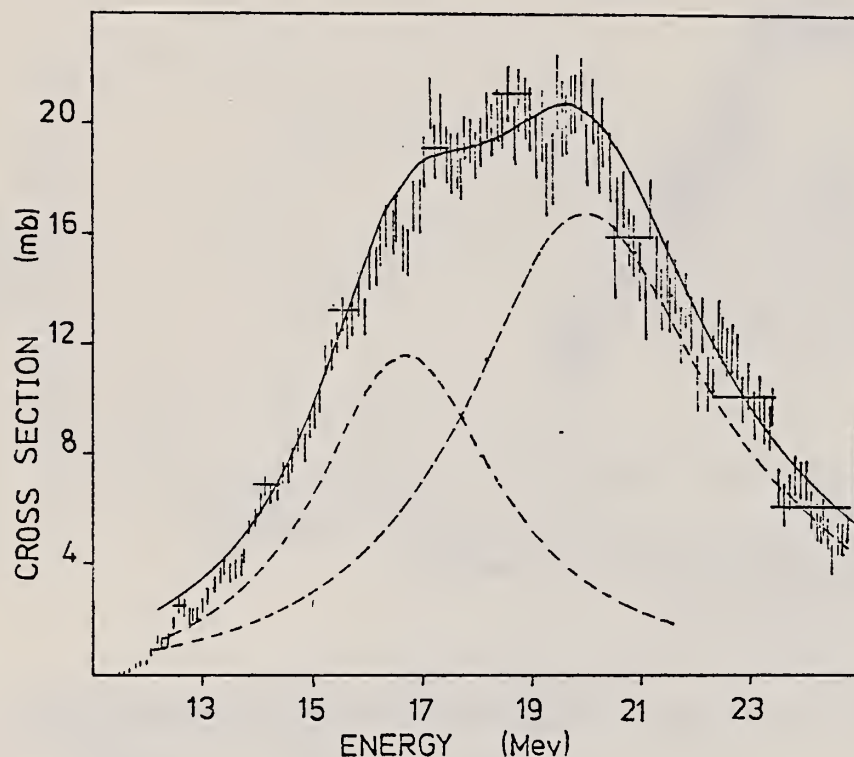
METHOD

REF. NO.

73 Sa 8

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	11- 25	C	11- 25	BF3-I		4PI



The total photoneutron cross section $\sigma(\gamma, n) + \sigma(\gamma, np) + \sigma(\gamma, 2n)$ for ^{45}Sc . The horizontal bars indicate the resolution width. The smooth curve represents the Danos model fit which is the sum of the two dashed Lorentz curves.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
* G,N	ABX	11- 28	D	11- 28	BF3-I		4PI
** G,2N	ABX	21- 28	D	21- 28	BF3-I		4PI

* 906+
** 907

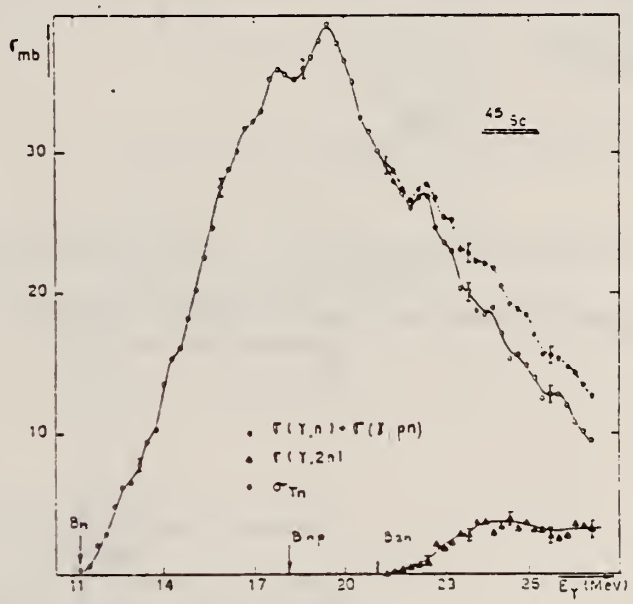


Fig. 13. Photoneutron cross sections $\sigma_{\gamma n}$, $[\sigma_\gamma(n) + \sigma_\gamma(2n)]$ and $\sigma_\gamma(2n)$ of ^{45}Sc .

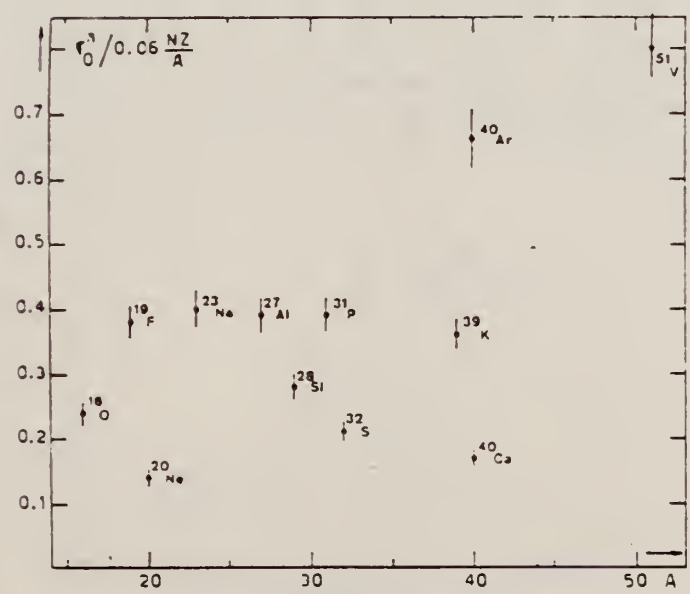


Fig. 22. Ratio of experimental integrated photoneutron cross section σ_0^n over the Thomas, Reiche and Kuhn sum rule $[0.06 NZ/A]$. Numerical values and upper integration limits E_M are taken from table 3. Also $\Delta\sigma_0^n = \pm 7\%$ for all nuclei.

(over)

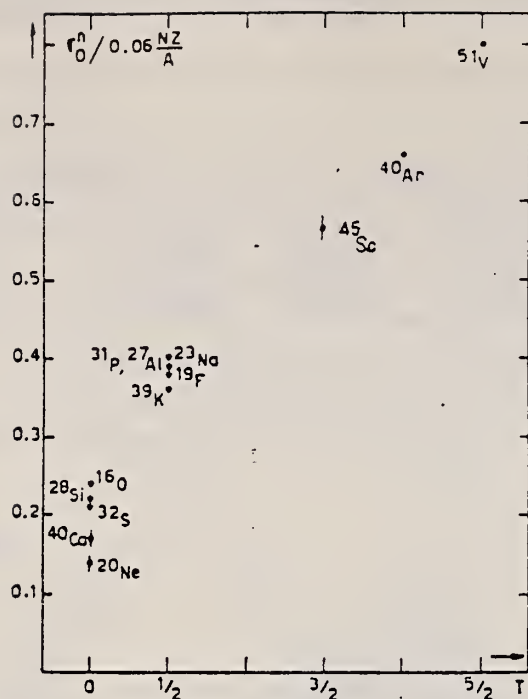


Fig. 24. The $[\sigma_0^n / (0.06 NZ/A)]$ ratio as a function of isospin T . Possible overall errors of $\pm 7\%$ are to be applied to all nuclei shown.

TABLE 3
Experimental integrated photoneutron cross sections $\sigma_0^n = \int_0^{E_M} \sigma_{Tn}(E) dE$ compared with the classical sum rule $[0.06 NZ/A]$ of Thomas, Reich and Kuhn

	$T=0$					$T=\frac{1}{2}$					$T=\frac{3}{2}$	$T=2$	$T=\frac{5}{2}$
Nucleus	^{16}O	^{20}Ne	^{28}Si	^{32}S	^{40}Ca	^{19}F	^{23}Na	^{27}Al	^{31}P	^{39}K	^{45}Sc	^{40}Ar	^{51}V
σ_0^n (MeV · mb)	58 ± 4	42 ± 3	94 ± 7	98 ± 7	100 ± 7	108 ± 7	137 ± 9	158 ± 10	182 ± 12	210 ± 14	383 ± 25	393 ± 28	602 ± 42
$\sigma_0^n / (0.06 NZ/A)$	0.24	0.14	0.22	0.21	0.17	0.38	0.40	0.39	0.39	0.36	0.57	0.66	0.3
E_M (MeV)	30	26.7	30	30	29.5	29	30	30	29	30	28.1	26.7	28

ELEM. SYM.	A	Z
Sc	45	21

METHOD

REF. NO.
75 Er 2
egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	THR-800	C	100-800	ACT-I		4PI

ISOMER RATIO

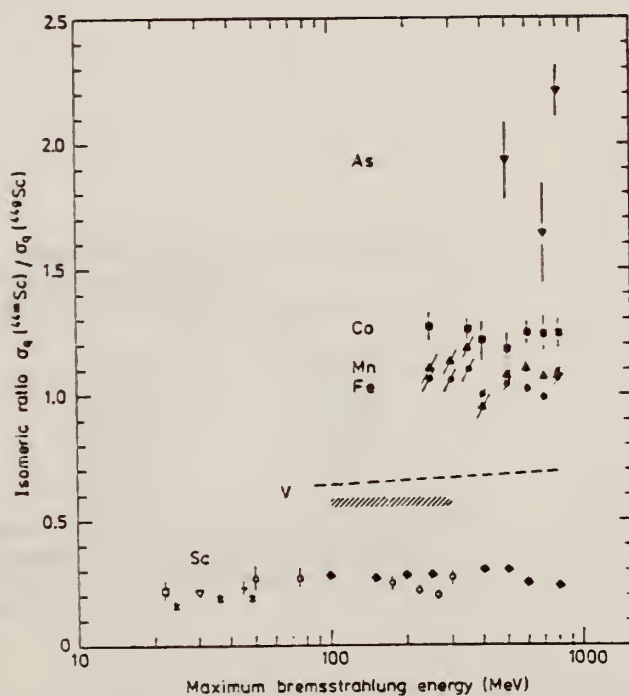


Fig. 6. Isomeric ratio $\sigma_q(^{44m}\text{Sc})/\sigma_q(^{44}\text{Sc})$ versus bremsstrahlung end-point energy for the different targets. Sc target: \diamond - this work, \square - ref. ¹⁵, \times - ref. ¹⁶, ∇ - ref. ¹⁷, $+$ - ref. ¹⁸, \circ - ref. ¹⁹; V target: dashed curve - ref. ²⁰, dashed area - ref. ²¹; Fe target: \bullet - this work; Mn target: \blacktriangle - this work; Co target: \blacksquare - this work; As target: \blacktriangledown - this work.

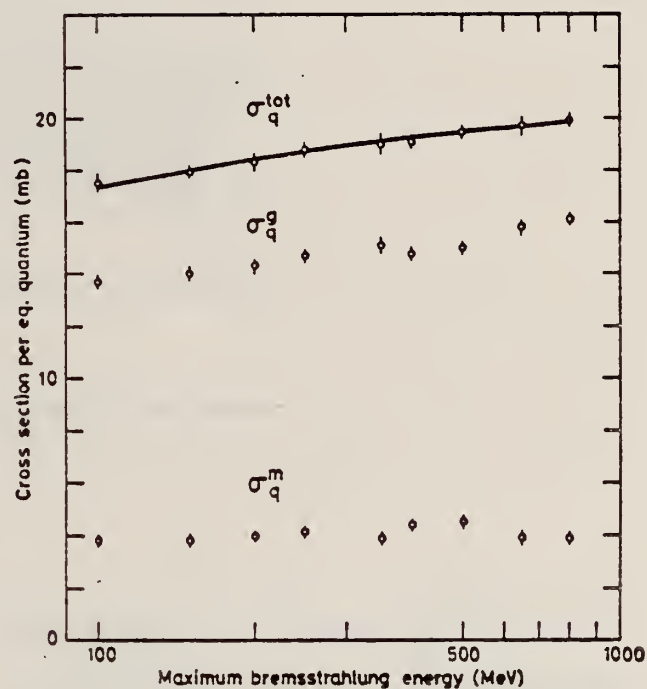


Fig. 2. Yield curves for the reactions $^{45}\text{Sc}(\gamma, n)^{44m}\text{Sc}$, $^{45}\text{Sc}(\gamma, n)^{44}\text{Sc}$ and $^{45}\text{Sc}(\gamma, n)^{44}\text{Sc}$. The solid curve shows the result calculated from giant resonance data plus the contribution from pion production processes.

(over)

TABLE 2
Comparison between experimental and calculated cross sections and isomeric ratios

Target	$\bar{\sigma}_{exp}$ (mb)	σ_{NIC} (mb)	$\bar{\sigma}_{SE}$ (mb)	$\sigma(m)/\sigma(g)_{exp}$	$\sigma(m)/\sigma(g)_{calc}$
	250-800 MeV	400 MeV	250-800 MeV	250-800 MeV	400 MeV
⁴³ Sc	≈ 0.5	0.58 ± 0.05		≈ 0	0.05
⁵¹ V	≈ 0.5	0.48 ± 0.05	0.47	0.7	0.72
⁵⁵ Mn	0.40 ± 0.14	0.59 ± 0.05	0.28	1.08 ± 0.04	1.04
Fe	0.40 ± 0.14		0.26	1.00 ± 0.05	
⁵⁹ Co	0.26 ± 0.10	0.34 ± 0.04 $0.65 \pm 0.07^*)$	0.18	1.26 ± 0.06	1.12 1.15 ^{*)}
⁷⁵ As		0.01 ± 0.01	0.044	1.9 ± 0.3	

*) 325 MeV.

- 15) S. A. Steinberg, B. Sc. thesis, Univ. of Illinois, 1963, unpublished (value taken from ref. ¹⁹))
- 16) J. R. Tatarczuk and H. A. Medicus, Phys. Rev. 143 (1966) 818
- 17) T. Kato and Y. Oka, Talanta 19 (1972) 515
- 18) R. Völpe, Nucl. Phys. A182 (1972) 411
- 19) W. B. Walters and J. P. Hummel, Phys. Rev. 150 (1966) 867
- 20) B. Bülow, Lund, private communication (preliminary results)
- 21) R. A. Meyer, thesis, Univ. of Illinois, 1963, unpublished

ELEM. SYM.	A	Z
Sc	45	21
REF. NO.		hmg
75 Me 4		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	1- 3	C	0- 3	SCD-D		DST
		(.72-2.092)		(.8-2.2)			

TABLE II. Comparison of the mean lifetimes determined in the resonance fluorescence experiments with the results of the Doppler shift attenuation measurements.

5 LEVELS .72-2.09 MEV

E_{level} (keV)	I_{exc}	Γ_0/Γ	Res. Fl.	Mean lifetimes (fs)	
				DSAM (Ref. 1)	DSAM (Ref. 2)
720	$\frac{5}{2} - a$	1.00	320 ± 30	...	220 ± 60
1237	$\frac{11}{2} - b$	1.00	2630 ± 200	...	1100 ± 200
1409	$\frac{7}{2} - c$	0.89	400 ± 30	< 170*	600 ± 300
1663	$\frac{9}{2} - b$	0.74	151 ± 13	...	110 ± 30
2092	$\frac{5}{2} - d$	0.83	8 ± 1	12 ± 3	...

* Reference 5.

^b References 5, 6.

^c References 3, 5.

^d References 7-9.

* This value differs from the limit given in the abstract of Ref. 1; it takes into account the error quoted in Table I of Ref. 1.

TABLE I. Comparison of the results of the nuclear resonance fluorescence experiments.

E_{level} (keV)	$g\Gamma_0^2/\Gamma$ (meV)	
	Ref. 2	Present work
720	1.58 ± 0.16	1.50 ± 0.20
1237	0.38 ± 0.02 ^a	0.35 ± 0.07
1409	1.36 ± 0.11 ^a	1.27 ± 0.12
1663	3.2 ± 0.3	2.8 ± 0.3
2095	47 ± 2	40 ± 4

^a The Γ_0 's deduced in Table I of Ref. 2 from the $g\Gamma_0^2/\Gamma$ values are incorrect. The authors apparently multiplied by g instead of dividing by g .

- ¹R.L. Schulte et al., Phys. Rev. C9, 1436 (1974).
- ²R.G. Arnold et al., Phys. Rev. C7, 1490 (1973).
- ³N.J.A. Rust et al., Nucl. Phys. A219, 232 (1974).
- ⁵W.M. Zuk et al., Aust. J. Phys. 24, 13 (1971).
- ⁶Z.P. Sawa et al., Nucl. Phys. A205, 257 (1973).
- ⁷G. Bergdolt et al., Nucl. Phys. A211, 486 (1973).
- ⁸R.L. Schulte et al., Can. J. Phys. 52, 131 (1974).
- ⁹G. Hardie et al., Phys. Rev. C10, 1829 (1974).

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, P	ABX	18	D	18	SCD-D		90

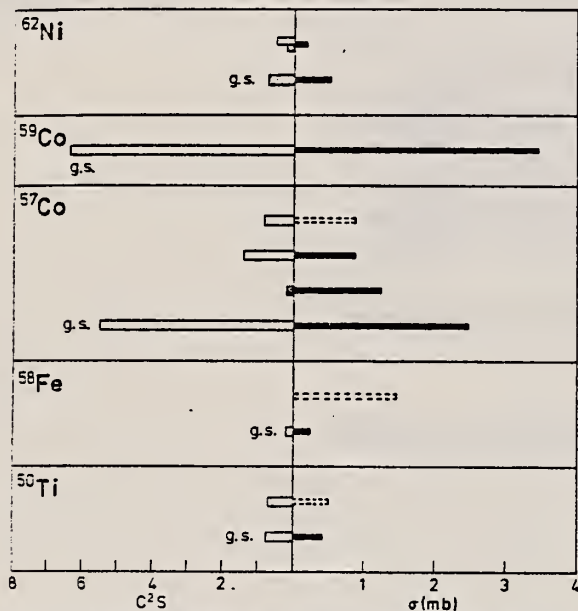
18 = 17.6 MEV

Fig. 5. Correlation between the spectroscopic factors and the cross-sections measured in this work. Open staples indicate $\ell_p = 3$ pick-up and cross hatched staples $\ell_p = 1$ pick-up. Dashed staples indicate that the cross section is uncertain due to the subtraction of a large back-ground

Table 2

Daughter nucleus	Level		σ^a (mb)
	(MeV)	J^π	
^{44}Ca	0	0^+	$\leq 0.2^b$
	1.16	2^+	$\leq 0.5^b$
^{50}Ti	0	0^+	0.41 ± 0.05
	2.68	4^+	$(0.5)^c$
^{58}Fe	0	0^+	0.23 ± 0.08
	3.24?	$0^+?$	$(1.5)^c$
^{57}Co	0	$7/2^-$	2.5 ± 0.2^d
	1.76	$3/2^-$	1.2 ± 0.3
	1.90	$7/2^-$	0.9 ± 0.2
	2.31	$7/2^-$	$(0.9)^c$
^{59}Co	0	$7/2^-$	3.5 ± 0.8
^{62}Ni	0	0^+	0.51 ± 0.09
	1.18	2^+	0.2 ± 0.1

^a The quoted errors are only those due to counting statistics.

^b Confidence level 95%.

^c Uncertain because of large background.

^d $\sigma = 2.4$ mb from [43].

43. Miyase, H., Oikawa, S., Suzuki, A., Uegaki, J., Saito, T., Sugawara, M., Shoda, K.: The photoproton reactions of Ni-isotopes. In: Proc. Int. Conf. Photoneuclear Reactions and Applications, Vol. I, p. 553. Livermore, USA 1973 (see Ref. 13)

REF.

N. M. Bachschi, P. David, J. Debrus, F. Lubke,
H. Mommsen, R. Schoenmackers, G. G. Jonsson, K. Lindgren
Nucl. Phys. A264, 493 (1976)

ELEM. SYM.	A	Z
Sc	45	21
REF. NO.		egf
76 Ba 7		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, JPKN	ABY	THR* 2	C	* 2	ACT-I		4PI

*GEV, J=1-10, K=1-19

Abstract: Yields and isomeric yield ratios of nuclei produced in the irradiation of ^{45}Sc and ^{63}Cu with bremsstrahlung of $E_{\gamma}^{\text{max}} = 2 \text{ GeV}$ have been measured by the activation method. The experimental yields are compared to predictions with a Rudstam formula modified to photonuclear reactions.

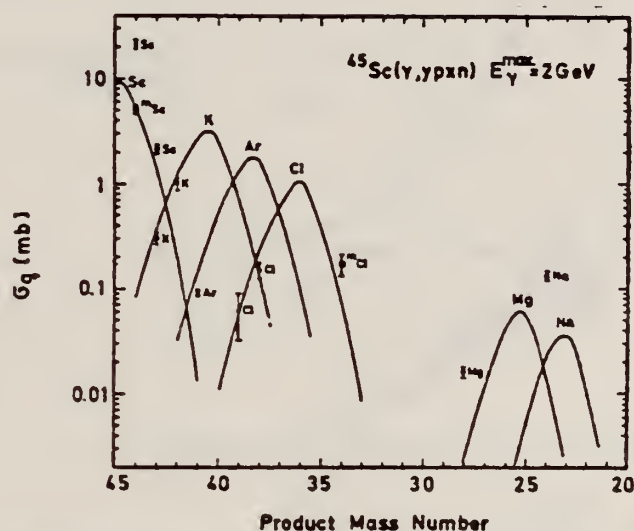


Fig. 1. Yields of nuclei produced in the irradiation of ^{45}Sc with bremsstrahlung of $E_{\gamma}^{\text{max}} = 2 \text{ GeV}$. The curves are calculated with eq. (1).

TABLE I
Cross section and isomeric ratios

Target	σ_q (ground state)	σ_q (isomer)	$\frac{\sigma_q^{\text{iso}}}{\sigma_q^{\text{gs}}}$
^{45}Sc	$^{44}\text{Sc} (2^-): 21.4 \pm 1.8 \text{ mb}$	$^{44\text{m}}\text{Sc} (6^-): 5.08 \pm 0.50 \text{ mb}$	0.24 ± 0.03
^{63}Cu	$^{52}\text{Mn} (6^+): 250 \pm 25 \text{ } \mu\text{b}$	$^{52\text{m}}\text{Mn} (2^-): 63 \pm 8 \text{ } \mu\text{b}$	0.25 ± 0.04
^{63}Cu	$^{44}\text{Sc} (2^-): 66.5 \pm 6.8 \text{ } \mu\text{b}$	$^{44\text{m}}\text{Sc} (6^-): 129 \pm 13 \text{ } \mu\text{b}$	1.9 ± 0.3

ELEM. SYM.	A	Z
Sc	45	21
REF. NO.		egf
77 01 1		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, P	ABX	14-25	D	14-25	MAG-D		90

Abstract: The cross sections of the (e, e'p) reaction on ^{44}Ca , ^{45}Sc and ^{46}Ti have been measured and used to deduce (γ , p) cross sections. Together with (γ , n) cross sections from others, these data allow an estimate of the T_+ and T_- GDR cross sections. The experimental results seem to be consistent with the theory on the isospin splitting. The (γ , p_0) or (γ , $p_0 + p_1$) and (γ , z_0) cross sections have also been measured. The ratio $\sigma(\gamma, p_0)/\sigma(\gamma, p)$ indicates a contribution of a statistical nature in the T_+ GDR region and some additional direct modes in the T_- GDR region. The contribution of one (^{45}Sc) or two (^{46}Ti) extra protons is discussed and it is found that the valence nucleons contribute to GDR in an independent way.

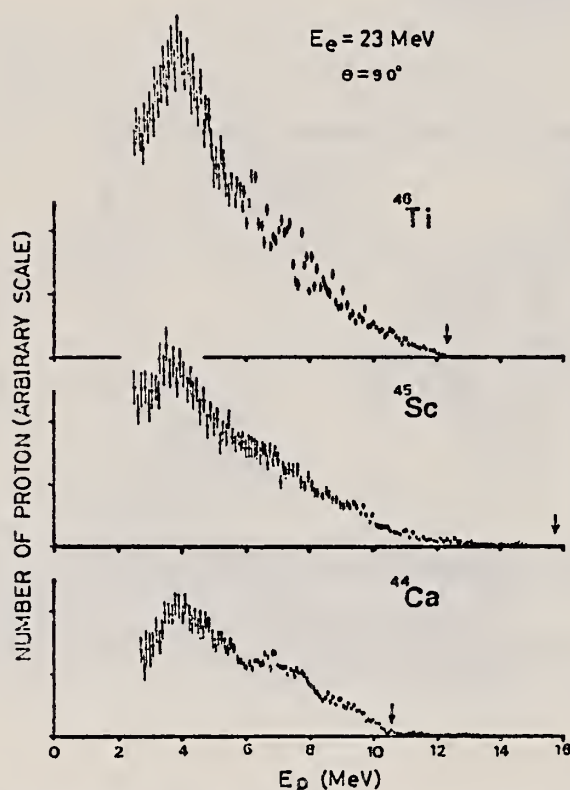


Fig. 4. Example of proton energy distribution obtained with 23 MeV electron beam. Arrows show the proton end point energy.

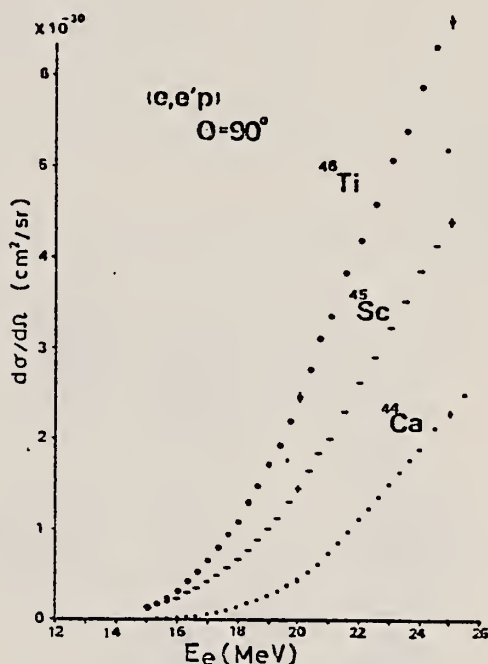


Fig. 5. The differential cross sections at $\theta = 90^\circ$ of the (e, e'p) reaction.

(over)

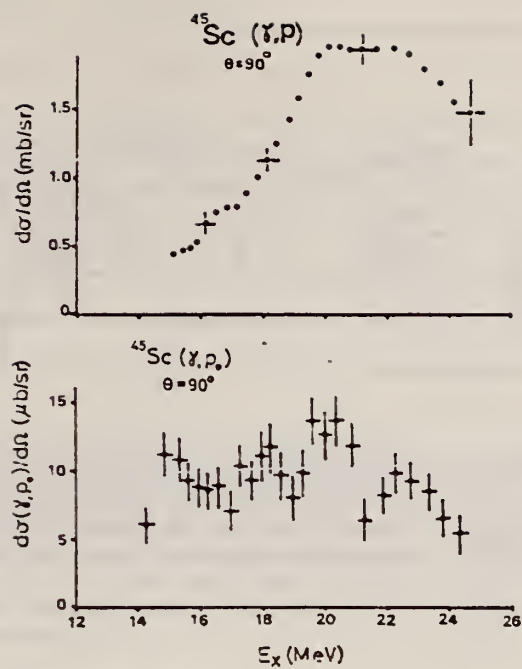


Fig. 7. The differential cross sections at $\theta = 90^\circ$ of the (γ, p) and (γ, p_0) reactions of ^{45}Sc .

REF. V.I. Noga, S.A. Pashchuk, Yu.N. Ranyuk, P.V. Sorokin
Yad. Fiz. 34, 1431 (1981)
Sov. J. Nucl. Phys. 34, 792 (1981)

ELEM. SYM.	A	Z
Sc	45	21
REF. NO.		egf
81 No 1		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G,N	RLY	11-260	C	165-260	ACT=I		4PI
E,N	RLY	11-259	D	165-260	ACT-I		4PI

BRMS/E YIELD

The induced-activity method has been used to study the reaction $^{45}\text{Sc}(e,e')^{45}\text{Sc}$. The targets were bombarded by an electron beam at energies 165, 195, 225, and 260 MeV. The use of paired targets of scandium, separated by a converter of tantalum, permitted determination of the ratio of the cross sections for photo- and electrodisintegration of the nuclei. Comparison of the experimental data with theoretical calculations indicates a dominant role of $E1$ transitions and a small admixture of $E2$ transitions in the reactions studied.

PACS numbers: 25.20. + y, 25.30. - c, 27.40. + z

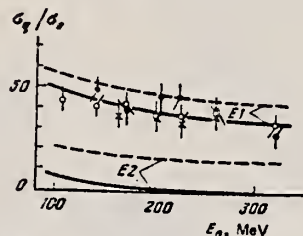


FIG. 2. The ratio σ_g/σ_e as a function of the electron energy.
Points: \circ — ^{63}Cu — ^{63}Cu , \bullet — ^{12}C — ^{11}C , \times — ^{45}Sc — ^{45}Sc .

REF. D. Ryckbosch, E. Van Camp, R. Van de Vyver, E. Kerkhove,
P. Van Otten, P. Berkvens, H. Ferdinande
Phys. Rev. C26, 448 (1982)

ELEM. SYM.	A	Z
Sc	45	21

METHOD

REF. NO.	egf
82 Ry 4	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P0	ABX	15-25	C	17-25	SCD-D		DST
G,PL	ABX	15-25	C	17-25	SCD-D		DST

The absolute (γ, p_0) differential cross sections for ^{45}Sc were measured at bremsstrahlung end point energies between 17 and 25 MeV. Using an artificially constructed pseudo-monoenergetic photon spectrum, absolute cross sections for various semidirect photoproton reaction channels were also determined. The general structure in the total (γ, p) cross section is discussed in terms of isospin and deformation effects. The direct, preequilibrium and equilibrium contributions to the photoproton decay of the giant dipole resonance equal about 35, 20, and 45%, respectively, of the total energy-integrated (γ, p) cross section. Comparison is made with the predictions of the exciton model.

NUCLEAR REACTIONS $^{45}\text{Sc}(\gamma, p)$, $E = 15.6 - 25$ MeV, $\theta = 37^\circ - 143^\circ$; measured $\sigma(E; \theta)$ absolutely. Deduced $\sigma(E; p_1)$, $\sigma(E)$, direct-semidirect cross section, isospin splitting, preequilibrium decay. Natural target.

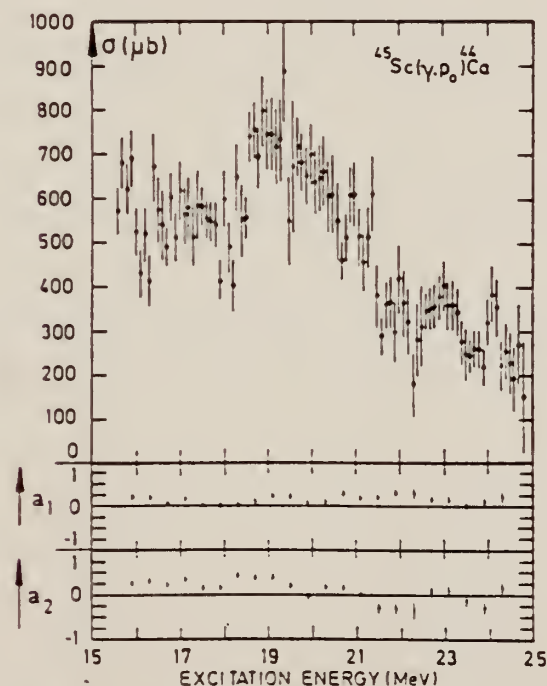


FIG. 2. The upper part of the figure shows the absolute $^{45}\text{Sc}(\gamma, p_0)^{44}\text{Ca}$ cross section, while in the lower part the angular distribution coefficients $a_1(E)$ and $a_2(E)$, as a function of excitation energy are depicted.

L=S,D,F P-HOLE STATES

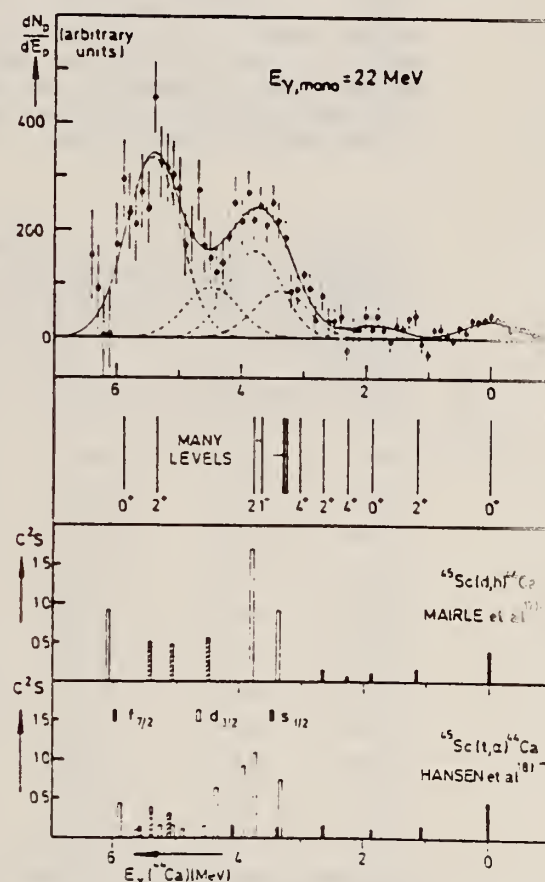


FIG. 3. The ^{45}Sc photoproton energy distribution corresponding to a monoenergetic photon spectrum with $E_{\gamma, \text{mono}} = 22$ MeV; the energy scale represents excitation energy in the residual nucleus ^{44}Ca . In the lower part of the figure the ^{44}Ca level scheme is shown, together with the experimentally determined (Refs. 17 and 18) values of the spectroscopic factors for proton-hole states.

(OVER)

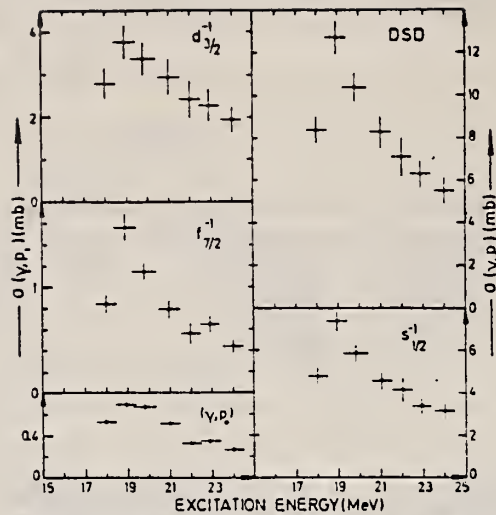


FIG. 4. The absolute cross sections for the $^{45}\text{Sc}(\gamma, p)$ reaction, leading to $f_{7/2}$, $d_{3/2}$, and $s_{1/2}$ proton-hole states in ^{44}Ca , together with their sum which represents the direct-semidirect photoproton cross section. The (γ, p_0) cross section, on which the other cross sections are normalized, is also shown explicitly.

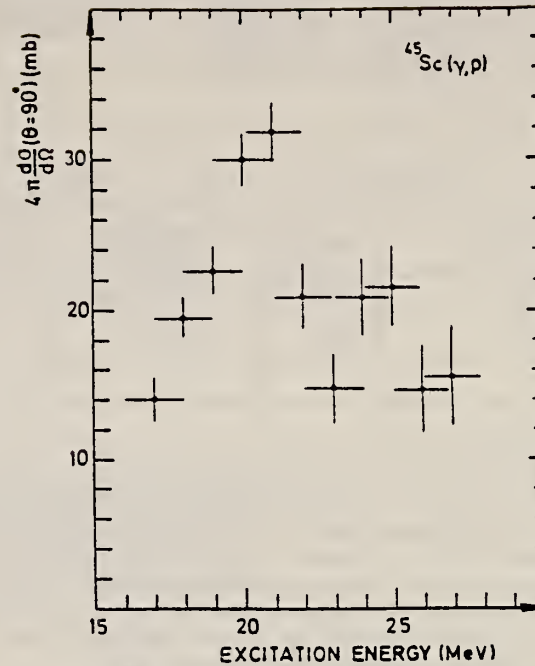


FIG. 5. The 90° differential total (γ, p) cross section, multiplied by 4π , as a function of excitation energy.

TABLE I. Comparison of our integrated cross sections, leading to specific proton-hole states in ^{44}Ca , with the spectroscopic factors as determined by Mairle *et al.*¹⁷

E_x (^{44}Ca) (MeV)	(l, j) (from Ref. 17)	c^2S (from Ref. 17)	$\int_{18}^{24} \sigma(\gamma, p_i) dE$ (mb MeV)
0.0	$3, \frac{7}{2}$	0.40	3.35 ± 0.05
1.16	$3, \frac{7}{2}$	0.15	(0.24 ± 0.06)
1.88	$3, \frac{7}{2}$	0.11	2.42 ± 0.18
2.29	$3, \frac{7}{2}$	0.07	
2.66	$3, \frac{7}{2}$	0.16	
3.37	$2, \frac{1}{2}$	0.92	10.52 ± 0.59
3.78	$2, \frac{3}{2}$	1.70	8.89 ± 0.76
4.48	$0, \frac{1}{2}$	0.55	9.49 ± 0.62
5.07	$0, \frac{1}{2}$	0.46	
5.43	$0, \frac{1}{2}$	0.50	23.73 ± 0.81
6.10	$2, \frac{3}{2}$	0.92	

Sc
A=47

Sc
A=47

Sc
A=47

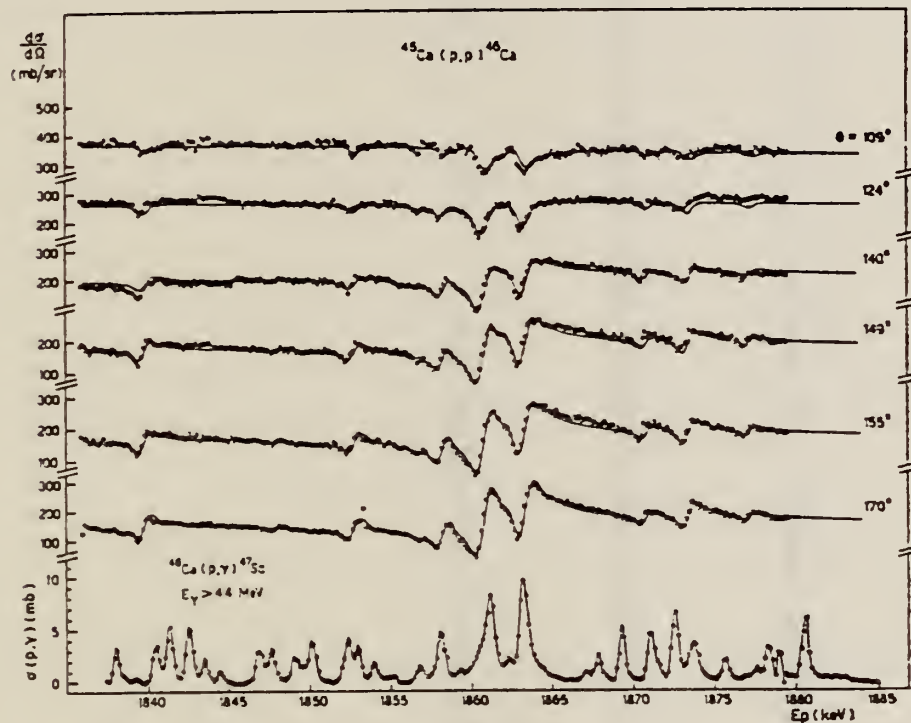
METHOD

REF. NO.

75 Vi 2

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	LFT	10	D	1- 2	NAI-D		55



PROTON E 1.82-1.90 MEV

Fig. 2. Excitation function for protons elastically scattered from ^{46}Ca at six backward angles and for capture γ -rays ($E_\gamma > 4.4$ MeV) from the $^{46}\text{Ca}(p, \gamma)^{47}\text{Sc}$ reaction measured in steps of 160 eV. The solid lines in the (p, p) data are theoretical excitation functions with the parameters given in table 1 folded with a Gaussian excitation distribution of 0.75 keV.

TABLE 2

Resonance widths and fine-structure parameters of $^{47}\text{Sc}(1)$ and $^{49}\text{Sc}(0)$ isobaric analogue states

Channel	J^π	E_A (keV)	Δ_A (keV)	Γ_s (keV)	γ_n^2 (keV)
$^{46}\text{Ca}+p$	$\frac{3}{2}^-$	1863	-77	5.3	0.02
$^{48}\text{Ca}+p$	$\frac{1}{2}^-$	1975	-8	1.5	0.03

(over)

TABLE 3

Partial Γ_γ from the $p_{\frac{1}{2}}^+$ IAS in $^{46}\text{Ca}(p, \gamma)$ for transitions to lower states in ^{47}Sc ; $B(\text{M1, IAS} \rightarrow \Gamma)$ is calculated summing the partial widths for the three resonance components and multiplying with the proton width ratio 1.6 (from table 1)

$E_{\text{res.}}$ (keV)	1858	1861	1863	
Γ_p (eV)	150	600	400	
Γ_γ total (eV)	0.56	1.53	1.33	
E_Γ (keV)	Γ_γ (meV)	Γ_γ (meV)	Γ_γ (meV)	$B(\text{M1, IAS} \rightarrow \Gamma)$ ($10^{-3} \mu_0^2$)
0	10	241	49	
767	8	21	35	
808	9	67	73	24
1297	32	26	67	24
1391	10	135	74	
1405	18	23	31	14
1797	21	96	27	32
2003	6	31	40	
2207	12	21	62	
2499		18	20	11
2528		29	13	13
2650		33	15	15
2810	15	9	62	
2836	21	16	30	
2909	10	20	39	
2941	15	60	45	41
3133	28	28	31	32
3205	12	28	9	19
3262	6		38	
3290	11	24	19	22
3576	18	15	20	23
3728	9		11	10
4019	12	42	30	46
4085	9	13	31	30
4099	6	21	15	25
4408		8	11	13
4475	6	10	6	15
4553	44		14	
4609	18	37	26	62
4631		18	34	39
4690	8	31	22	47
4721	27	24		41
4792		38	18	45
4802		31	42	60
4831	5	36	21	53
4956	16	23	35	68
4998	15	15	20	46
5151	12	48	36	97
5509	12	37	30	100
5600	19	45	48	150
6383	20	58	42	275
6584	17	10	12	105
6724	28	24	26	234

Sc
A=49

Sc
A=49

Sc
A=49

METHOD

[Page 1 of 2]

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	SPC	10-11	D	1	NAI-D	1-12	DST

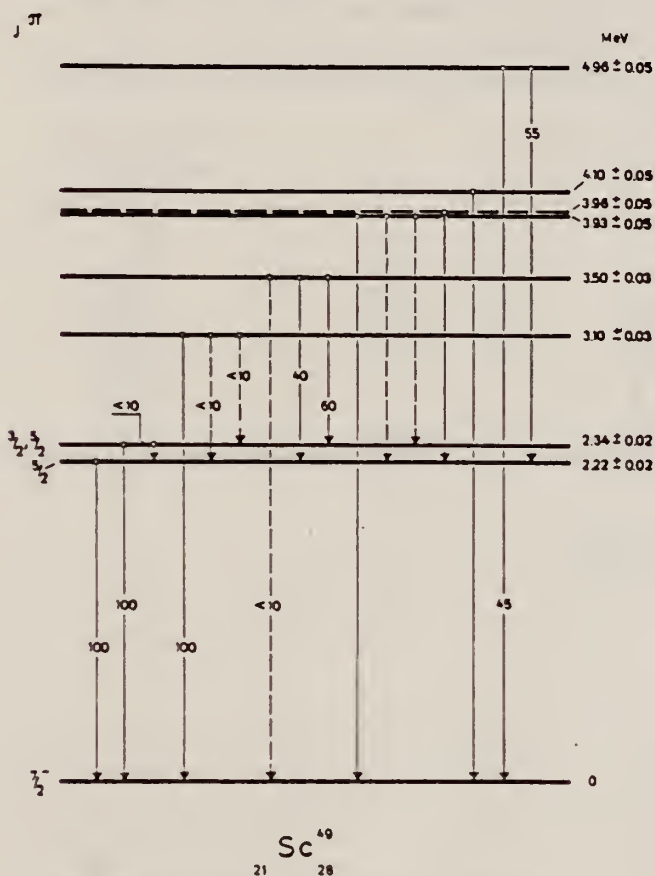


Fig. 7. The level scheme of Sc^{48} from the present work.

Table 2. Observed transitions at the 1012 keV resonance.

Gamma transition	Relative intensity
$r=0$	6 ± 1
$r=2.22$	100
$r=2.34$	< 7
$r=3.50$	37
$r=3.93$	40

Table 3. Observed transitions at the 1117 keV resonance.

Gamma transition	Relative intensity
$\gamma-0$	< 4
$\gamma-2.22$	52
$\gamma-2.34$	100

Table 4. Observed transitions at the 1213 keV resonance.

Gamma transition	Relative intensity
$r-0$	< 6
$r-2.22$	< 10
$r-2.34$	100
$r-3.10$	24
$r-3.50$	32
$r-3.93$	34

Table 5. Observed transitions at the 1340 keV resonance.

Gamma transition	Relative intensity
$r-0$	< 4
$r-2.22$	100
$r-2.34$	20
$r-3.10$	14
$r-3.50$	58

ELEM. SYM.	A	Z
Sc	49	21
REF. NO.		JDM
66 Du 2		

METHOD

[Page 2 of 2]

REACTION	RESULT	EXCITATION	SOURCE	DETECTOR		ANGLE
				TYPE	RANGE	

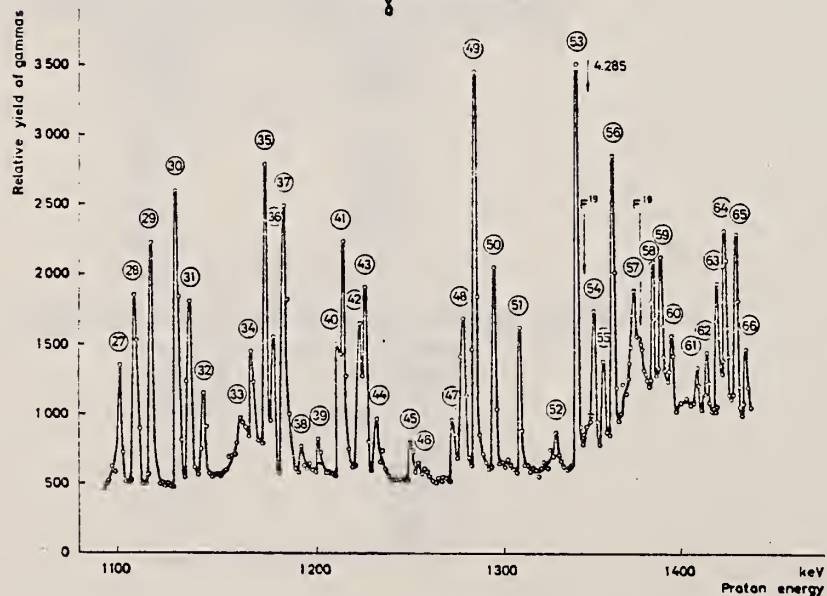
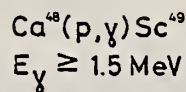
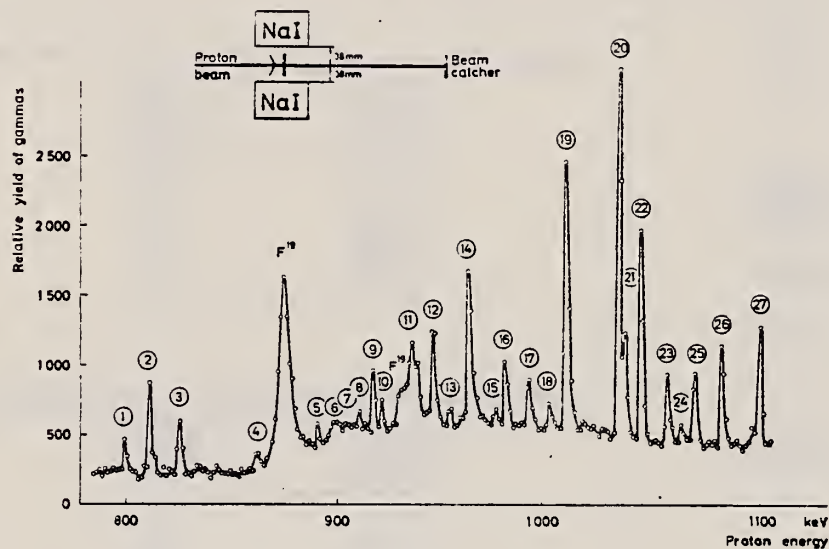
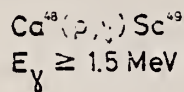


Fig. 1. The excitation curve of the $\text{Ca}^{48}(p,\gamma)\text{Sc}^{49}$ -reaction. In the insert the detector arrangement is shown.

REF.

C. Chasman, K. W. Jones, R. A. Ristinen, and J. T. Sample
Phys. Rev. Letters 18, 219 (1967)

ELEM. SYM.

A

Z

Sc

49

21

METHOD

REF. NO.

67 Ch 1

JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P.G	LFT	12	D	2	SCD-D		90

Table I. Transitions from analogs of the Ca^{49} ground state in Sc^{49} to low-lying excited states in Sc^{49} .

Sc^{49} final-state ^a excitation energy (keV)	l^a	$J^\pi{}^a$	S^a	Assumed multipolarity of gamma transition	Γ_ω^b (eV)	$E_p(\text{lab})$ = 1.968 MeV		$E_p(\text{lab})$ = 1.977 MeV	
						Γ_γ (eV)	$\Gamma_\gamma/\Gamma_\omega$	Γ_γ (eV)	$\Gamma_\gamma/\Gamma_\omega$
0.0	3	$(7/2^-)$	1.0	E2	1.8	≤ 0.7	≤ 0.4	3.5	1.9
2233.0	(2)	$(3/2^+)$	0.05	E1	745.0	1.1	0.002	0.9	0.001
2382.0	(0)	$(1/2^+)$	0.005	E1	710.0	2.1	0.003	1.2	0.002
3092.0	1	$(3/2^-)$	0.68	M1	12.9	2.7	0.2	≤ 0.5	≤ 0.04
3819.0	3	$(5/2^-)$	0.15	M1	9.8	≤ 0.4	≤ 0.04	2.8	0.3
3923.0 ^c	...					...		...
4004.0 ^c	...					...		...
4080.0	3	$(5/2^-)$	0.20	M1	8.9	3.9	0.4	3.0	0.3

ELEM. SYM.	A	Z
Sc	49	21
REF. NO.		
71 Pa 3		hmg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	REL	13-27	D	4-18	NAI-D		105

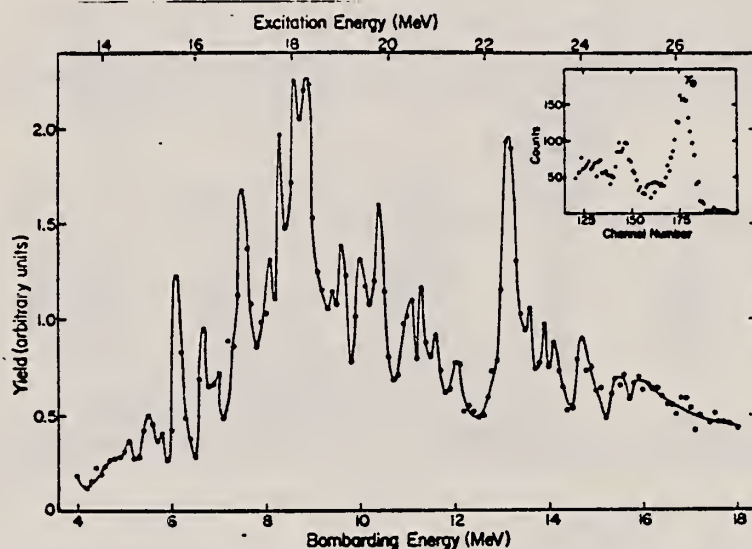


FIG. 1. Excitation function of the γ_0 yield obtained at 105° in the reaction $^{48}\text{Ca}(\rho, \gamma_0)^{48}\text{Sc}$. The insert shows the high-energy part of the γ -ray spectrum.

TABLE I. Separation energies $\Delta E = E_+ - E_-$ of the $T+1$ and T components of the GDR observed from proton capture into various nuclei with ground-state isospin T . \bar{V} is obtained from Eq. (2) in the text.

Nucleus	ΔE (MeV)	T	\bar{V} (MeV)	Ref.
^{42}Ca	3.0 ± 0.2	1	63 ± 4	13
^{49}Sc	4.8 ± 0.2	$7/2$	52 ± 2	Present
^{60}Ni	3.0 ± 0.2	2	60 ± 4	5
^{64}Zn	3.2 ± 0.3	2	68 ± 6	Present
$^{64}\text{Zn}^{*a}$	2.9 ± 0.3	2	62 ± 6	Present
^{88}Sr	3.7 ± 0.5	6	47 ± 6	1
^{89}Y	3.9 ± 0.5	$11/2$	54 ± 7	2
$^{89}\text{Y}^{*a}$	3.8 ± 0.4	$11/2$	52 ± 6	2
^{90}Zr	3.9 ± 0.5	5	58 ± 7	1
^{91}Nb	3.6 ± 0.7	$9/2$	59 ± 10	2

^aFirst excited state.

METHOD

REF. NO.

Page 1 of 2.

73 Ad 14

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	SPC	12	D	2	SCD-D		DST

12=11.559 MEV, J-PI

Table II. Partial Γ_r (meV) to the excited states in ^{49}Sc .

Ex. (keV)	$J^{\pi\pi}$	E_p (keV)					SUM	Summed M1 strength (W. U.)
		1960	1964	1975	1982	1991		
0	7/2-	5(meV)		127	4		0.136(eV)	E2
2226	1/2+	16	66	82	3	6	0.173	E1
2371	3/2+	25	36	59	4		0.124	E1
3032	3/2-	10	85	34	5	28	0.162	1.2×10^{-2}
3515	3/2-	23	81	58	16	29	0.207	1.9×10^{-2}
3804	5/2-, 7/2-	22	63	146	16	48	0.295	2.3×10^{-2}
3991		27	51	147	14	34	0.273	3.0×10^{-2}
4068	5/2-	25	156	259	39	54	0.533	6.2×10^{-2}
4491	1/2-, 3/2-	*	69	78	*	*	0.147	2.0×10^{-2}
4736	5/2-	40	80	182	43	30	0.375	5.7×10^{-2}
6305	5/2	33	71	67	42	40	0.253	8.6×10^{-2}
6412	3/2- (7/2-)	71	124	292	55	31	0.573	2.0×10^{-1}
6504	3/2-	53	196	538	66	53	0.911	3.4×10^{-1}
6723	3/2-	87	214	431	64	42	0.835	3.6×10^{-1}
6934	5/2-	69	303	593	40	36	1.041	5.3×10^{-1}
7062	1/2-	59	160	331	34	41	0.625	3.3×10^{-1}
7192	5/2	53	118	246	28	26	0.476	2.8×10^{-1}
7226	5/2	41	131	263	48	42	0.550	3.2×10^{-1}
Total		674	2004	3933	521	540		

* The transition to the 4491 keV state was obscured by the presence of Doppler-broadened lines from the reaction $^{19}\text{F}(p, \alpha)^{16}\text{O}$ due to a target contaminant.

* See ref. 7.

The uncertainties on the Γ_r are dominated by the uncertainties on Γ_{γ} , which sum up to $\approx 20\%$ in the cases of 1960 and 1975 keV resonances. In other three resonances, the uncertainties on the Γ_r are due to the uncertainties on Γ_{γ} and intensities of gamma rays. The uncertainty on the individual Γ_r ranged from 20 to 100%.

⁷ M. Adachi and H. Taketani: J. Phys. Soc. Japan 35 (1973) 317.

(over)

Table I. Analysis of angular distribution data.

Final state (keV)	A_2	Assumed spin	Mixing ratio	I -value*	Assigned spin
0	0.000 ± 0.050	<u>7/2</u>	$-0.035^{+0.050}_{-0.049}$ or $1.74^{+0.19}_{-0.21}$	$37-12$	7/2
1022	-0.384 ± 0.060	<u>1/2</u>	$-0.065^{+0.033}_{-0.032}$ or $2.02^{+0.18}_{-0.16}$	$0, 10, 12 (2)^{21}$	
		3/2	$0.593^{+0.083}_{-0.068}$ or $3.44^{+0.82}_{-0.63}$		1/2
1371	0.039 ± 0.084	1/2	$-0.316^{+0.045}_{-0.048}$ or $4.53^{+1.13}_{-0.76}$	$(0), 3, 2^{10}, 12$	
		<u>3/2</u>	$0.198^{+0.057}_{-0.054}$ or $-17.6^{+8.5}_{-292.5}$		3/2
3032	-0.075 ± 0.164	1/2	$-0.228^{+0.086}_{-0.088}$ or $3.24^{+1.29}_{-0.75}$	$17-10$	
		<u>3/2</u>	$0.311^{+0.132}_{-0.113}$ or $-17.6^{+6.0}_{-17.6}$		3/2
3515	0.389 ± 0.376	1/2	$-0.497^{+0.222}_{-0.341}$ or $-3.83^{+3.83}_{-5.9}$	1^{10}	
		<u>3/2</u>	$0.007^{+0.242}_{-0.279}$ or $-3.99^{+2.24}_{-115.4}$		3/2
		5/2	$3.1 > \delta > 0.1$		
3804	0.502 ± 0.446	5/2	$2.73 > \delta > 0.14$	3^8-10	
		7/2	$1.75 > \delta > -0.09$		7/2, 5/2
4068	-0.006 ± 0.063	<u>5/2</u>	$0.081^{+0.059}_{-0.055}$ or $3.29^{+0.79}_{-0.57}$	3^8-10	
		7/2	$-0.149^{+0.061}_{-0.060}$ or $2.02^{+0.33}_{-0.27}$		5/2
4736	-0.029 ± 0.095	5/2	$0.061^{+0.087}_{-0.081}$ or $3.55^{+1.55}_{-0.90}$	$3^3, 10$	
		7/2	$-0.171^{+0.092}_{-0.090}$ or $2.14^{+0.59}_{-0.42}$		5/2
6306	-0.153 ± 0.149	1/2	$-0.187^{+0.078}_{-0.079}$ or $2.84^{+0.86}_{-0.57}$		
		3/2	$0.371^{+0.131}_{-0.110}$ or $9.76^{+377.3}_{-5.13}$		
		<u>5/2</u>	$-0.044^{+0.127}_{-0.125}$ or $5.84^{+15.80}_{-2.57}$		5/2
		7/2	$0.288^{+0.141}_{-0.151}$ or $2.96^{+2.16}_{-0.94}$		
6412	0.292 ± 0.098	1/2	$-0.435^{+0.059}_{-0.063}$ or $8.76^{+7.48}_{-2.73}$	$1, 10 (4)^{21}$	
		<u>3/2</u>	$0.069^{+0.062}_{-0.063}$ or $-5.37^{+1.40}_{-2.74}$		3/2 (7/2)
		5/2	0.237		
		7/2	0.058		
6504	0.546 ± 0.051	1/2	$-0.614^{+0.040}_{-0.044}$ or $-37.0^{+19.8}_{-}$	1^{10}	
		<u>3/2</u>	$-0.098^{+0.035}_{-0.036}$ or $-2.74^{+2.79}_{-0.33}$		3/2
6728	0.204 ± 0.064	1/2	-0.382 ± 0.037 or $6.23^{+1.65}_{-1.08}$	$(1), ^9 (3)^{10}$	
		<u>3/2</u>	$0.124^{+0.041}_{-0.040}$ or $7.72^{+1.85}_{-3.51}$		
		5/2	$0.299^{+0.093}_{-0.075}$ or $1.81^{+0.35}_{-0.31}$		3/2
		7/2	$0.070^{+0.085}_{-0.073}$ or 1.25 ± 0.20		

ELEM. SYM.	A	Z
Sc	49	21

METHOD

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REF. NO.

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REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

Final state (keV)	A_2	Assumed spin	Mixing ratio	I -value*	Assigned spin
6934	-0.055 ± 0.055	1/2	-0.239 ± 0.029 or $3.36^{+0.37}_{-0.31}$	$1^7(1)^{10}(4)^{10}$	5/2
		3/2	$0.297^{+0.040}_{-0.039}$ or 13.8		
		5/2	$0.038^{+0.049}_{-0.046}$ or $3.88^{+0.92}_{-0.65}$		
		7/2	$-0.195^{+0.052}_{-0.053}$ or $2.28^{+0.35}_{-0.28}$		
7062	-0.492 ± 0.094	1/2	$-0.005^{+0.056}_{-0.052}$ or $1.75^{+0.24}_{-0.21}$		1/2
		3/2	$0.758^{+0.310}_{-0.147}$ or $2.39^{+0.89}_{-0.81}$		
		5/2	$-0.345^{+0.091}_{-0.105}$ or $-8.43^{+3.71}_{-20.3}$		
7192	-0.125 ± 0.091	1/2	-0.202 ± 0.048 or $2.97^{+0.52}_{-0.40}$		5/2
		3/2	$0.349^{+0.074}_{-0.067}$ or $12.0^{+33.3}_{-5.3}$		
		5/2	$-0.021^{+0.073}_{-0.076}$ or $5.41^{+3.07}_{-1.80}$		
7226	-0.084 ± 0.054	1/2	$-0.223^{+0.023}_{-0.029}$ or $3.19^{+0.33}_{-0.28}$		5/2
		3/2	$0.318^{+0.041}_{-0.039}$ or $18.1^{+33.2}_{-7.3}$		
		5/2	0.014 ± 0.046 or $4.32^{+1.11}_{-0.76}$		

* Deduced from stripping or pick up reaction, see ref. 7-12.

- 7) T. B. Cline, W. J. McDonald, W. K. Dawson and G. C. Netherton: Nuclear Phys. A113 (1968) 553.
- 8) D. D. Armstrong and A. G. Blair: Phys. Rev. 149 (1965) B1216.
- 9) J. R. Enklire, A. Marinov and J. P. Schiffer: Phys. Rev. 142 (1966) 633.
- 10) G. Brue, H. Faggit, Ha Duc Long and P. Russell: CERN-N-1332, p. 124.
- 11) J. L. Yriena and G. R. Satchler: Phys. Rev. 134 (1964) B974.
- 12) E. Newman and J. C. Herbert: Nuclear Phys. A119 (1968) 376; E. Hinterberger, G. Maire, V. Schmidt-Rohr, P. Turek and G. J. Wagner: Z. Phys. 202 (1967) 236.

ELEM. SYM.	A	Z
Sc	49	21
REF. NO.		
76 Di 2		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	LFT	15	D	6- 7	NAI-D		DST

Abstract: Gamma rays have been observed from the $^{48}\text{Ca}(p, \gamma)$ reaction de-exciting analogs of the 4.005 MeV (f_7^-) and 4.024 MeV (g_3^-) states in ^{49}Ca . The resonances were observed at $E_p(\text{c.m.}) = 5.933 \pm 0.005$ and 5.992 ± 0.005 MeV, respectively, with total widths 39 ± 5 and 18 ± 5 keV. The corresponding ground-state γ -widths were inferred to be 17 ± 5 and 22 ± 22 eV. Decays of the lower resonance to excited states of ^{49}Sc were also observed. A tentative lower limit of 1.7 eV was placed on the width of the transition to the $\frac{3}{2}^-$ (3.08 MeV) level. The upper ($\frac{3}{2}^+$) γ -ray (g.s.) resonance is depleted by a factor of 10-20 by the giant dipole resonance and cannot be used easily to extract structural information. The (tentative) lower limit on the M1 decay of the lower ($\frac{3}{2}^-$) resonance to the $\frac{3}{2}^-$ state ($E_x = 3.08$ MeV) implies a strong $1f_7$ neutron admixture in the lower state which is not borne out by theoretical estimates of the effects of the core polarization. The M1 decay of this same resonance to the ground state is calculated to be 9-13 eV, with the Arima-Horie estimate for the effects of core polarization, and 16 eV in a three-particle, two-hole configuration mixing shell-model calculation. Both figures are consistent with the measurement and confirm the existence of strong magnetic moment renormalization effects.

TABLE 1

Angular distribution coefficients for the ground-state transition expressed in the form $d\sigma/d\Omega = \sum_{L=0}^2 A_L P_L(\cos \theta)$

$E_p(\text{lab})$ (MeV)	A_0	A_1	A_2
5.982	10.0 ± 1.2	1.7 ± 0.5	4.8 ± 1.0
6.040	15.1 ± 1.8	2.0 ± 0.5	3.6 ± 0.8
6.063	29.0 ± 4.0	7.2 ± 1.0	2.4 ± 1.0
6.080	23.0 ± 3.0	1.2 ± 1.0	-1.2 ± 1.6
6.097	16.6 ± 2.0	-1.0 ± 0.2	-1.1 ± 0.2
6.120	31.0 ± 4.0	-1.9 ± 0.5	-3.1 ± 0.9
6.160	12.6 ± 1.5	-1.3 ± 0.3	-0.2 ± 0.4

Values of A_L are given in $\mu\text{b/sr}$.

TABLE 3

Radiation widths extracted from the data

Transition	$\Gamma_p \Gamma_\gamma^a$ (keV \cdot eV)	Γ_p^b (keV)	Γ_γ (eV)	$S\Gamma_{\text{r.p.}}^{\text{c}}$ (eV)
$\frac{3}{2}^- \rightarrow \frac{1}{2}^-(0)$	420 ± 63	24 ± 5	17 ± 5	33 (M1)
$\frac{3}{2}^- \rightarrow \frac{3}{2}^+(2.37)$	34 ± 10	24 ± 5	1.4 ± 0.5	
$\frac{3}{2}^- \rightarrow \frac{3}{2}^-(3.08)$	> 40	24 ± 5	> 1.7	0 (M1)
$\frac{3}{2}^+ \rightarrow \frac{1}{2}^-(0)$	58 ± 58	2.7 ± 0.8	22 ± 22	254 (E1)

The single-particle estimate is discussed in the text. See table 4 also.

^{a)} This work.

^{b)} Ref. ⁴⁾.

^{c)} Values of S from (d, p) reaction ¹⁵⁾.

EXC 15.55, 15.61 MEV

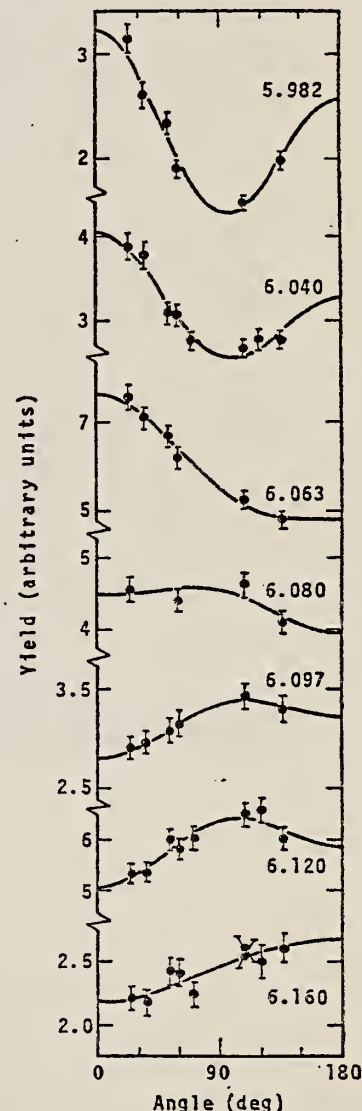


Fig. 4. Angular distributions of the ground-state γ -decays in the $^{48}\text{Ca}(p, \gamma)^{49}\text{Sc}$ reaction. The distributions are labeled by the lab proton energy in MeV. The curves are Legendre-polynomial fits to the data with parameters listed in table 1.

⁴ K.W. Jones et al., Phys. Rev. 145, 894 (1966).

¹⁵ E. Kashy et al., Phys. Rev. 135, B865 (1965).

TITANIUM

 $Z=22$

Titanium was discovered in 1790 by William Gregor, an English clergyman who was also a mineralogist and an amateur chemist. Gregor's analysis of the black sand found in his own parish along the beach in the county of Cornwall showed 45.26 percent of a white metallic oxide, up to that time unrecognized. A few years later, Martin Klaproth found a new element in rutile found in Boinile, Hungary. Klaproth acknowledged Gregor's priority and suggested the name "titanic earth" or titanium, from the Titans of Greek Mythology. Almost 100 years passed before Lars Nilson and Otto Pettersson finally prepared a metal, 95 percent pure, by reducing titanium tetrachloride with sodium in an airtight cylinder.

Method Betatron; proton yield; angular distribution; scintillator;
ion chamber

Ref. No.	
63 Mi 5	NVB

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
----------	-----------------	-------	----------	------------------	--------	-------

Ti(γ ,xp)

Bremss.
22

Angular distribution:

$$Y(\theta) = a + b \sin^2 \theta (1 + p \cos \theta)^2$$

where $a = 51 \pm 0$, $b = 47 \pm 15$,
 $p = 0.0 \pm 0.2$, and $b/a = 0.9 \pm 0.4$.

Yield ($E_p > 8$ MeV):

$$(0.44 \pm 0.1) 10^5 \text{ protons/mole-r}$$

Yield ($3.7 < E_p < 14$): $(5.4 \pm 0.5) 10^5$

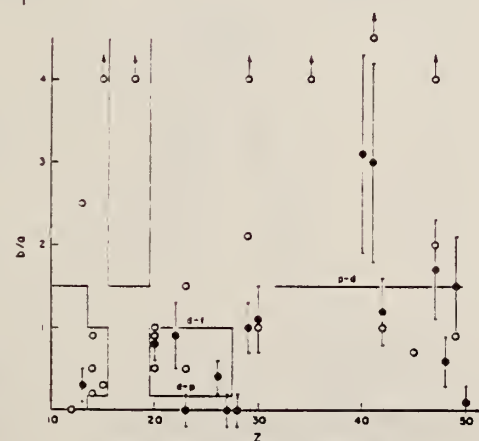
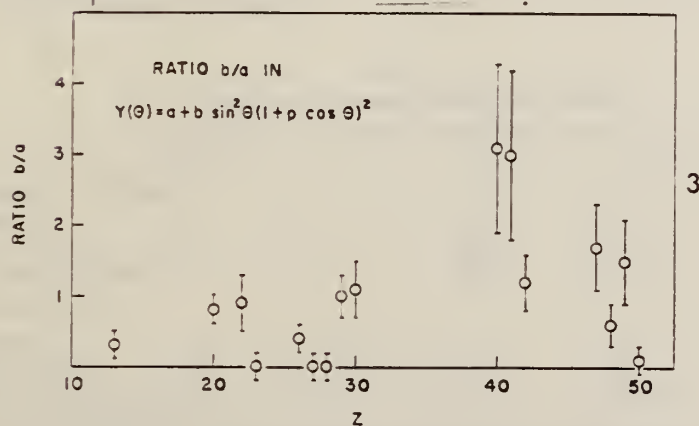
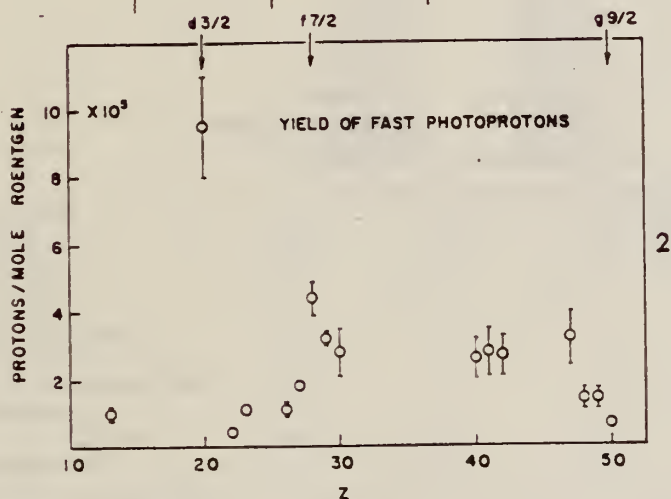


FIG. 2. The yields of fast photoprotons ($E_p > 8$ Mev) obtained from targets of various elements when irradiated with 22-Mev bremsstrahlung. The target thicknesses range from 551 to 572 mg/cm² (about 8 Mev for protons). The errors noted are statistical.

FIG. 3. The anisotropy coefficient b/a for fast photoprotons ($E_p > 8$ Mev) from 16 elements. The errors noted are statistical.

FIG. 4. The values of the fast photoproton anisotropy coefficient b/a found by the present authors (●) and other workers (○) in the region of the periodic table $10 < Z < 50$. Arrows indicate off-scale points. The references to the results of other workers are given in Table II. The demarcations are explained in the text.

METHOD

REF. NO.

64 A1 5

JOC

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XN	NØX	THR-34	C	34	THR-I	6-	DST

TABLE I

Summary of present experimental data at 34 MeV bremsstrahlung

Element		$-\frac{a_2}{a_0}$	$\frac{a_1}{a_0}$
^4Be		0.43 ± 0.02	0.05 ± 0.01
^{12}C		0.61 ± 0.04	0.09 ± 0.02
^{13}Al		0.39 ± 0.03	0.05 ± 0.01
^{11}Ti		0.34 ± 0.02	0.06 ± 0.01
^{14}Cr	34 MeV	0.33 ± 0.02	0.02 ± 0.01
	22 MeV	0.13 ± 0.07	-0.02 ± 0.03
^{18}Cu		0.36 ± 0.02	0.10 ± 0.01
^{50}Sn		0.38 ± 0.02	0.11 ± 0.01
^{14}Ba		0.39 ± 0.03	0.11 ± 0.02
^{75}Ta	Before installation of iron shielding	0.26 ± 0.04	0.13 ± 0.02
	After installation of iron shielding	0.27 ± 0.02	0.12 ± 0.01
^{81}Pb	target diameter 3.0 cm	0.39 ± 0.03	0.15 ± 0.02
	target diameter 1.5 cm	0.40 ± 0.03	0.19 ± 0.02
^{81}Bi		0.42 ± 0.03	0.17 ± 0.02

$$I = a_0 + a_1 \cos \theta + a_2 \cos^2 \theta$$

REF. J. A. Scheer, K. Schlupmann und F. Triantafyllidis Nucl. Phys. <u>56</u> , 113-116 (1964)			ELEM. SYM. A		Z
			Ti		22
METHOD Betatron			REF. NO. 64 Sc 1		JOC
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,A	SPC	THR - 33	C	33	90

ABS YIELD

TABELLE 1
Meßdaten und Ergebnisse

	Ti	Ni	Cu	Nb
Targetdicke (mg/cm ²)	2.08	1.52	9.90	8.87
Bestrahlungsdauer (h)	52.5	55.5	18.0	84.5
Registrierte Teilchenanzahl (4 ≤ E _x ≤ 12.6 MeV)	1861	2376	2333	1987
Lage des Maximums E _{max} der Energieverteilung (MeV)	6.4	8.2	8.5	11
Halbwertsbreite des Maximums (MeV)	2.8	2.8	4.0	3.5
Mittlerer Energieverlust im Target bei E _x = E _{max} (MeV)	0.4	0.25	1.7	1.1
Ausbeute in μb/MeV *)	22 ± 3.5	45 ± 7	23 ± 3.5	5.5 ± 0.8

*) Vgl. Bemerkung *) in Tabelle 2.

TABELLE 2
Vergleich der Ergebnisse verschiedener Autoren

E ₀ (MeV)	Ti	Ni	Cu	Nb
<i>Ausbeute (10³ × N₀/Mol. r)</i>				
Boulègue 31		58.7	50.8	
Diese Arbeit *) 32.5	48 ± 7	98 ± 15	50 ± 7.5	12 ± 1.8
Toms und McElhinney 21.5		39.4	26	4.6 ^{b)}
<i>Relative Ausbeute</i>				
Boulègue 31		1	0.87	
Kregar und Povh 30		1	0.54	
Diese Arbeit 32.5	0.49 ± 0.08	1	0.51 ± 0.08	0.12 ± 0.02
Toms und McElhinney 21.5		1	0.66	0.12 ^{b)}

*) Die Fehlerangaben beinhalten auch die Unsicherheit in der Absoluteichung der Intensität des γ-Strahles.

^{b)} Dieser Wert wurde aus nur 14 beobachteten Ereignissen bestimmt.

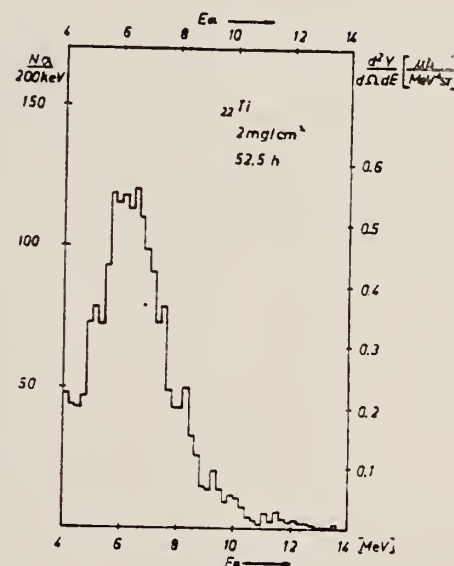


Abb. 1. Die erhaltenen Energie-Spektren der Photoalphateilchen aus Ti, Ni, Cu und Nb.

METHOD		Nuclear Resonance Scattering using N,G reactions.			
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR
			TYPE	RANGE	TYPE RANGE
G,G	RLX	5 - 10	D	5 - 10	NAI-D 5 - 10

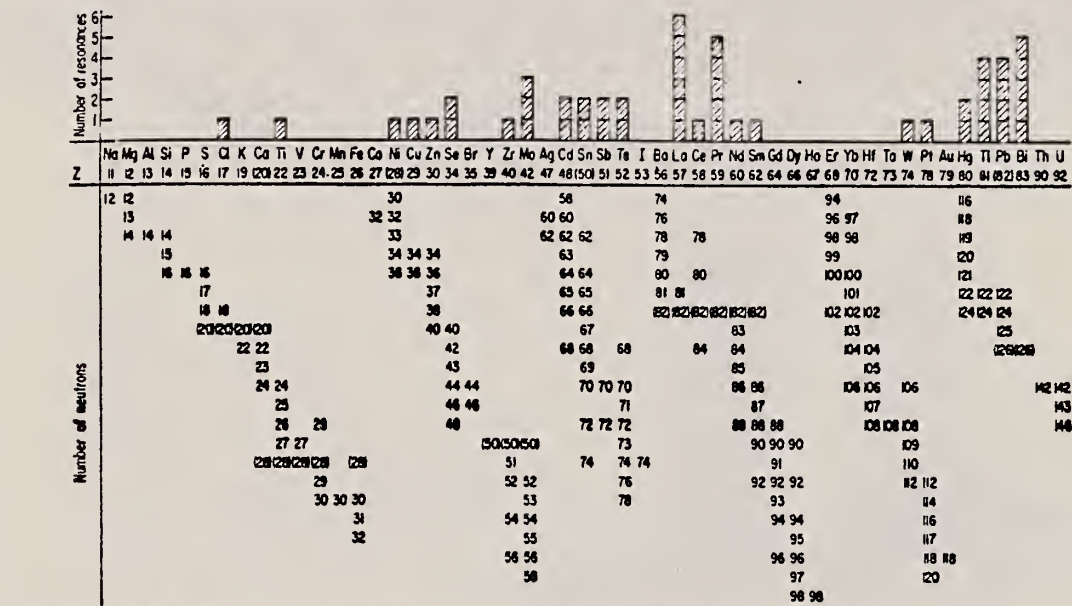


FIG. 3. Histogram of distribution of observed resonances among the different targets. The atomic number is given directly beneath the chemical symbol followed by the neutron numbers of the naturally occurring isotopes. Magic numbers are shown in brackets.

TABLE III. List of effective cross sections.

Scatterer	Energy (MeV)	Gamma source	σ (mb)	Scatterer	Energy (MeV)	Gamma source	σ (mb)
Sm ¹⁴⁴	8.997	Ni	100	Sn	7.01	Cu	110
Pr ¹⁴¹	8.881	Cr	9	Nd	6.867	Co	30
La	8.532	Ni	6	Pr ¹⁴¹	6.867	Co	3
Te	8.532	Ni	3 ^a	Te	6.7	Ni	...
Cu	8.499	Cr	24	La	6.54	Ag	12
Zr	8.496	Se	3050	Cd	6.474	Co	110
Zn	8.119	Ni	13	Mo	6.44	Hg	25 ^c
Se	7.817	Ni	50	La	6.413	Ti	72
Sb	7.76	K	90	Mo	6.413	Ti	10
Cd	7.64	Fe	40 ^b	Ti	6.413	Ti	25
Ni	7.64	Fe	7 ^c	W	6.3	Ti	...
Pr ¹⁴¹	7.64	Fe	12 ^c	Sb	6.31	Hg	6 ^c
Ti	7.64	Fe	370 ^c	Ti	6.31	Hg	2 ^c
La	7.634	Cu	7	Sn	6.27	Ag	75
Mo	7.634	Cu	11	Pb ²⁰⁸	6.15	Gd	...
Bi ²⁰⁹	7.634	Cu	4	Te	5.8	Ni	...
Te	7.528	Ni	66 ^d	La	6.12	Cl	35
Bi ²⁰⁹	7.416	Se	100	Pr ¹⁴¹	6.12	Cl	110
Cl	7.300	As	80 ^e	Pt	5.99	Hg	40 ^c
Pb ²⁰⁸	7.285	Fe	4100	Tl	5.99	Hg	5 ^c
Cl	7.285	Fe	34	Pb ²⁰⁸	5.9	Sr	...
Pr ¹⁴¹	7.185	Se	80	Ce	5.646	Co	17
Tl	7.16	Cu	120	Bi ²⁰⁹	5.646	Co	55
La	7.15	Mn	50	Pb ²⁰⁸	5.53	Ag	70
Bi ²⁰⁹	7.149	Ti	2000	Hg	5.44	Hg	75 ^c
				Hg	4.903	Co	385

^a High-energy component of a complex spectrum.
^b A broad scattered spectrum with no observable peak structure.
^c There are actually two lines of energies 7.647 and 7.633 MeV having equal intensities in the iron capture gamma spectrum. The cross section has therefore been corrected, although there is no possibility at present of deciding which line is responsible for each resonance.
^d Is probably an independent level in the complex spectrum of Ni γ rays on Te.
^e Rough estimate.
^f May be inelastic component from 7.528 level in Te.
^g The relative line intensities in this case are due to Groshev and co-workers.
^h No line is known for the source at this energy.
ⁱ Difficult to resolve among the many source lines present at this energy.

METHOD	REF. NO.	
Betatron; NBS ionization chamber	67 Co 1	JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	12-24	C	24	BF3-I		4PI

434

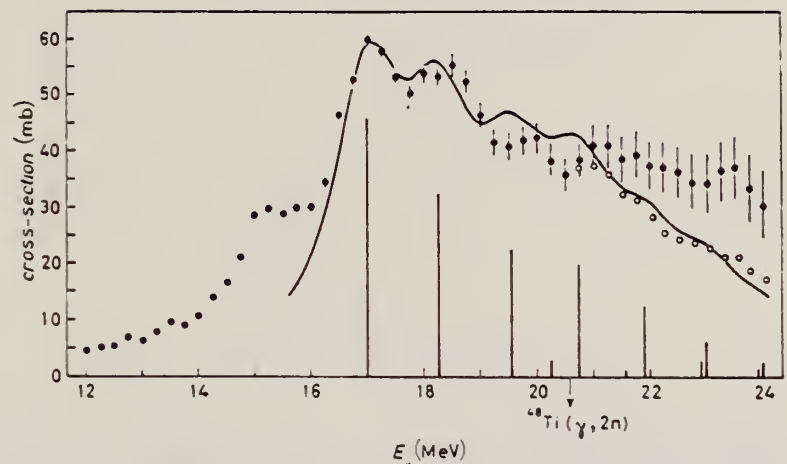


Fig. 1. - $(\gamma, 2n)$ cross-section for Ti. The dipole strengths, calculated for ^{48}Ti , are indicated by the vertical bars. Open circles represent the $(\gamma, 2n)$ cross-section corrected for neutron multiplicity. The level density parameter used has been taken from ref. (*).

METHOD

REF. NO.

69 Ok 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, TI 45	RLY	THR-60	C	30-60	NAI-D		4PI
G, SC 44	RLY	THR-60	C	30-60	NAI-D		4PI
G, P	RLY	THR-60	C	30-60	NAI-D		4PI
G, CA 47	RLY	THR-60	C	30-60	NAI-D		4PI

YLD REL 12C(G,N):

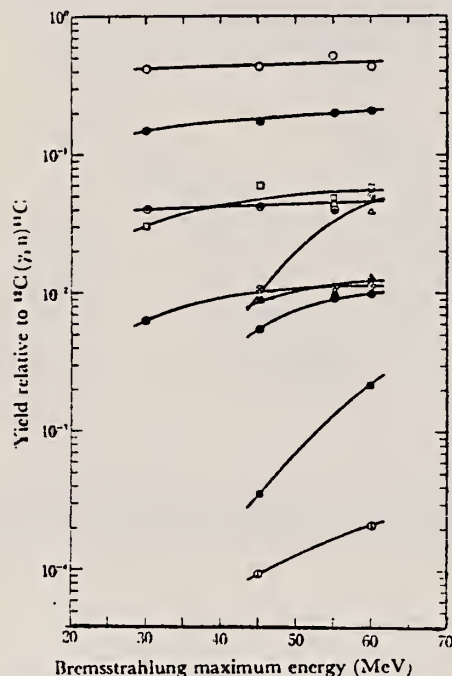


Fig. 6. The yield relative to $^{12}\text{C}(\gamma, n)^{11}\text{C}$ as a function of bremsstrahlung maximum energy.

- \circ : ^{45}Ti from titanium
 \bullet : ^{45}Sc from titanium
 \odot : ^{46}Sc from titanium
 \oplus : ^{47}Sc from titanium
 \otimes : ^{48}Sc from titanium
 \triangle : ^{46}V from vanadium
 \blacktriangle : ^{46}Sc from vanadium
 \square : ^{47}Sc from vanadium
 \blacksquare : ^{48}Sc from vanadium
 \odot : ^{47}Ca from titanium

TABLE 6. THE RELATIVE YIELDS FOR (γ, p) REACTIONS ON TITANIUM
NUCLEI EXPRESSED AS THOSE PER MOLE

Reaction	Yield per mole relative to $^{12}\text{C}(\gamma, n)^{11}\text{C}$			
	30 MeV	45 MeV	55 MeV	60 MeV
$^{47}\text{Ti}(\gamma, p)^{46}\text{Sc}$	5.4×10^{-1}	5.8×10^{-1}	5.4×10^{-1}	6.3×10^{-1}
$^{48}\text{Ti}(\gamma, p)^{47}\text{Sc}$	2.0×10^{-1}	2.4×10^{-1}	2.8×10^{-1}	2.8×10^{-1}
$^{49}\text{Ti}(\gamma, p)^{48}\text{Sc}$	1.2×10^{-1}	2.1×10^{-1}	2.2×10^{-1}	2.1×10^{-1}

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	ABX	12-30	C	32	NAI	12-30	DST

GETS G,G/ TO 2+

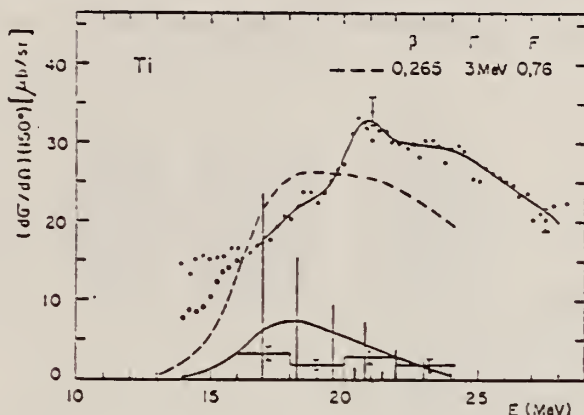


Fig. 4. Differential total scattering cross section at 150° for natural Ti. The full curve through experimental points is only a guide for the eyes. The vertical bars represent the relative strength of dipole levels calculated by the D.C.M. with parameters of table 1. Theoretical elastic plus inelastic scattering is computed from these levels with a common width Γ (dashed curve). Experimental inelastic scattering (histogram) and theoretical inelastic scattering to the first 2^+ (full curve) are shown in the lower part of the figure. Open circles give the cross section after background subtraction.

TABLE 4
Integrated inelastic scattering cross section

Nucleus	Limits of integration (in MeV)	Experimental ^{a)} $\int \sigma_i(E) dE$ (MeV \cdot μ b)	2^+	Theoretical ^{a)} 2^{++} (MeV \cdot μ b)	Total
Ti(48 Ti)	16 - 24	250 ± 50	425	109	534
51 V(52 Cr)	16.4 - 24.9	492 ± 50	509	116	579
Cr	16.4 - 23.4	431 ± 50	509	116	579
75 As(76 Se)	14.1 - 23.6	1254 ± 120	1373	414	1787
Se(80 Se)	14.1 - 24.6	1035 ± 100	1066	353	1419
89 Y					364
Cd(112 Cd)	13.6 - 23.3	3264 ± 240	1894	370	2264
In(114 Cd)	13.6 - 23.6	2840 ± 220	2173	388	2561
Sn(110 Sn)	14.2 - 24.2	2363 ± 220			643

^{a)} We assume an angular distribution of the form $1 + \frac{1}{3} \cos^2 \theta$.

METHOD

REF. NO.

71 Co 2

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABI	36-64	C	10-64	BF3-I		4PI

FAST N YIELD

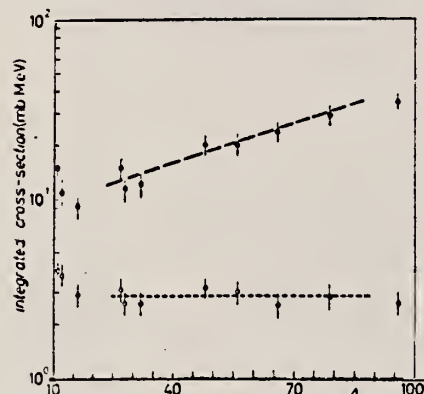


Fig. 2.

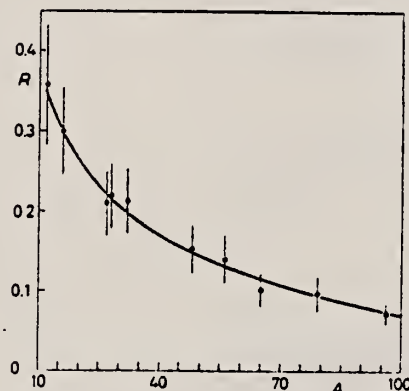


Fig. 3.

Fig. 2. - Experimental photoneutron cross-sections integrated over photon energy between 36 and 64 MeV and divided by NZ/A are plotted as a function of the mass number. Black dots are total cross-sections not corrected for neutron multiplicity; open circles represent fast neutron cross-sections (see text). The dashed lines are drawn only to guide the eye.

Fig. 3. - The ratio between 'fast' and total photoneutron integrated cross-sections as a function of the mass number A . The solid line represents a fit of the ratios calculated for some nuclei by taking into account the theoretical neutron energy spectra given by GABRIEL and ALSMILLER (*) and the efficiencies of our detector (see Fig. 1).

METHOD			REF. NO.		
			72 Ke 4		hmg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G.A	RLY	7-32	C	32	SCD-D
					DST

TABLE 3. Observed angular distribution parameters for 32 MeV electron energy

Element	A_0	A_1/A_0	A_2/A_0
Ti	7.03 ± 0.15	0.073 ± 0.052	-0.286 ± 0.073
V	2.58 ± 0.06	0.037 ± 0.042	-0.126 ± 0.069
Fe	10.22 ± 0.30	0.006 ± 0.043	-0.333 ± 0.072
Co	6.80 ± 0.20	0.022 ± 0.048	-0.016 ± 0.077
Ni	15.95 ± 0.49	0.051 ± 0.048	-0.213 ± 0.074
Cu	8.37 ± 0.28	0.076 ± 0.056	-0.035 ± 0.081
Zn	17.87 ± 0.61	0.004 ± 0.045	-0.270 ± 0.073
Ag	0.39 ± 0.01	0.115 ± 0.049	$+0.093 \pm 0.074$

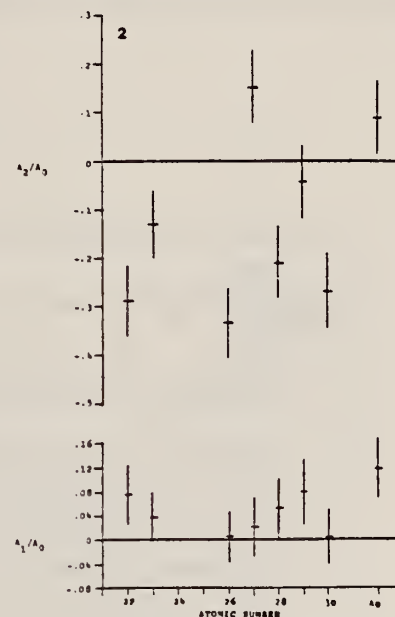


FIG. 2. Angular distributions for 32 MeV electron energy.

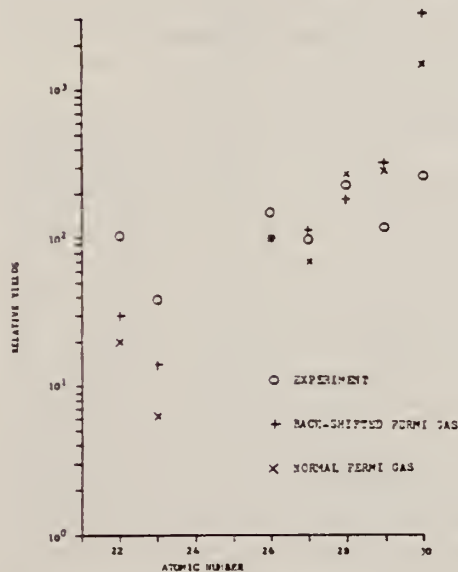


FIG. 13. Experimental and theoretical relative photo-alpha yields for 32 MeV electron beam energy.

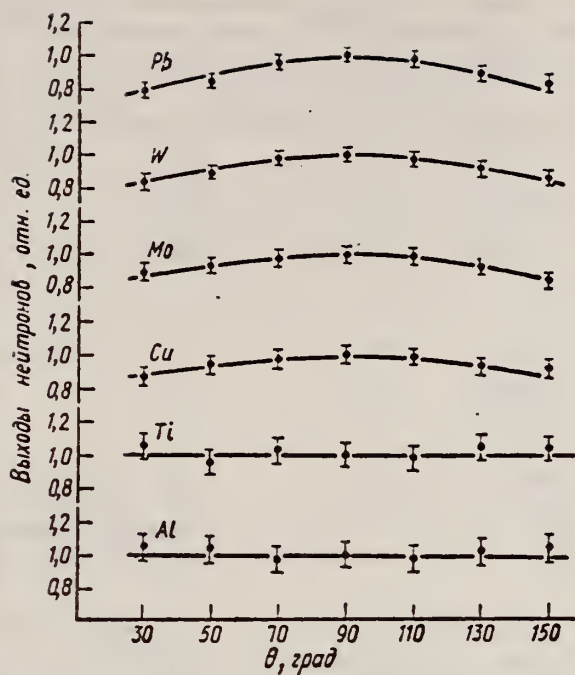
ELEM. SYM.	A	Z
Ti		22
REF. NO.		hmg
72 Ko 8		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NOX	8- 22	C	22	THR-I		DST

Мп-шень	Энергия элек- трон- нов, Мэв	Детек- тор	Угол, град							В/А
			30	50	70	90	110	130	150	
Al	22,5	P ³¹ (n, p)	1,05±0,08	1,03±0,08	0,97±0,08	1,0±0,08	0,98±0,08	1,02±0,08	1,04±0,08	Изотроп- ное
	22,5	Al ²⁷ (n, p)	0,90±0,15	0,95±0,15	1,02±0,15	1,00±0,14	0,96±0,13	1,07±0,13	1,01±0,13	»
Ti	22,5	P ³¹ (n, p)	1,04±0,07	0,96±0,07	1,03±0,07	1,00±0,07	0,98±0,07	1,05±0,07	1,03±0,07	»
	22,5	Al ²⁷ (n, p)	1,06±0,13	0,94±0,13	1,04±0,12	1,00±0,12	0,95±0,11	0,98±0,11	1,02±0,10	»
Cu	12,8	P ³¹ (n, p)	0,97±0,10	1,04±0,10	1,02±0,10	1,00±0,10	1,01±0,10	0,90±0,10	0,96±0,10	»
	17,0	P ³¹ (n, p)	1,03±0,07	0,97±0,07	1,00±0,07	1,00±0,07	1,06±0,07	0,95±0,07	0,88±0,07	»
	22,5	P ³¹ (n, p)	0,87±0,05	0,94±0,05	0,97±0,05	1,00±0,05	0,99±0,05	0,93±0,05	0,91±0,05	0,18±0,04
	22,5	Al ²⁷ (n, p)	0,75±0,09	0,86±0,07	0,93±0,06	1,00±0,05	1,02±0,05	0,94±0,04	0,90±0,04	0,23±0,06
Mo	22,5	P ³¹ (n, p)	0,90±0,05	0,93±0,05	0,98±0,05	1,00±0,05	0,99±0,05	0,92±0,05	0,84±0,05	0,21±0,04
	22,5	Al ²⁷ (n, p)	0,80±0,08	0,95±0,08	0,95±0,07	1,00±0,06	0,94±0,05	0,83±0,04	0,72±0,04	0,44±0,08
	22,5	Al ²⁷ (n, α)	0,72±0,08	0,84±0,08	0,89±0,08	1,00±0,08	0,93±0,08	0,87±0,08	0,63±0,05	0,73±0,18
W	22,5	P ³¹ (n, p)	0,85±0,04	0,90±0,04	0,93±0,04	1,00±0,04	0,98±0,04	0,92±0,04	0,87±0,04	0,25±0,04
	22,5	Al ²⁷ (n, p)	0,78±0,06	0,84±0,06	0,89±0,05	1,00±0,05	0,97±0,04	0,86±0,04	0,75±0,04	0,54±0,06
Pb	22,5	P ³¹ (n, p)	0,79±0,04	0,85±0,04	0,96±0,04	1,00±0,04	0,98±0,04	0,83±0,04	0,84±0,04	0,36±0,03
	22,5	Al ²⁷ (n, p)	0,70±0,09	0,81±0,08	0,94±0,07	1,00±0,06	0,94±0,06	0,80±0,05	0,69±0,05	0,69±0,12

(over)



Угловые распределения быстрых фотонейтронов из Al, Ti, Cu, Mo, W, Pb, облучаемых электронами с энергией 22,5 Мэв. Детектор ^{31}Si (n, p) ^{31}Si .

METHOD

REF. NO.

73 Ba 20

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, N	NOX	THR- 27	C	10- 27	BF3-I		4P

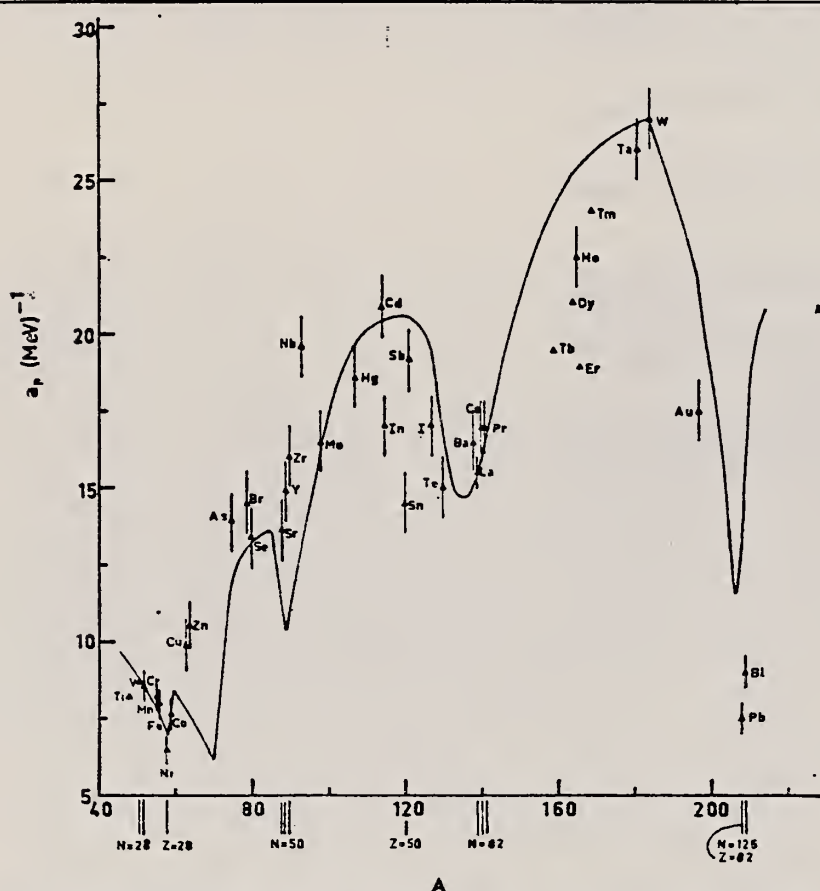


Fig. 12. Experimental values of the level density parameter a_p (Fermi gas formula plus pairing correction) versus atomic number A . The continuous curve is a least-squares fit to the data of a theoretical calculation from Newton ¹⁵.

- 1 H. Baba and S. Baba, Japan Atomic Energy Research Institute report JAERI-1183 (1969).
- 2 H. Baba, Nucl. Phys. A159, 625 (1970).
- 15 T.D. Newton, Can. J. Phys. 34, 804 (1956).

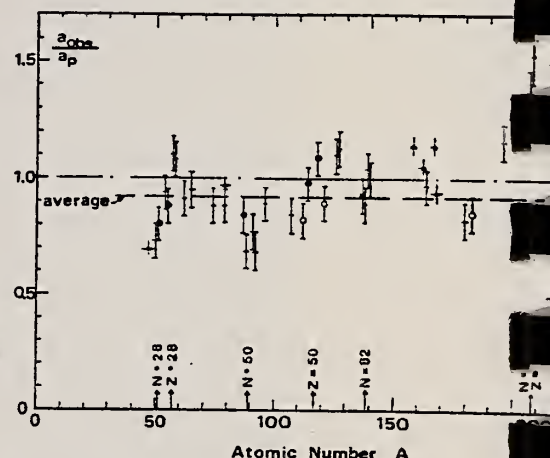


Fig. 15. Ratio a_{obs}/a_p versus atomic number A . Here a_{obs} is the level density parameter taken from the neutron resonance work of refs. ^{1,2}, and a_p is the level density parameter derived from the present (γ, n) work. Filled circles represent points where nuclei in the neutron resonance and in the (γ, n) experiment were the same. Open circles represent points where the respective nuclei were approximately matched. Triangles represent points which are based on measurement of neutron mean energies at two bremsstrahlung energies only.

(over)

TABLE 3

Comparison of experimental and theoretical data on nuclear level densities with Fermi gas formulae, and comparison of nuclear level density parameters from (γ, n) and n-resonance absorption experiments

Target	N (residual nucleus) ^{a)}		Goodness of fit ^{b)} no with p.c. p.c.		$\bar{E}_n(24)$ (MeV) ^{c)}	T (MeV) ^{d)}	a_p (MeV ⁻¹) ^{e)}	a_{obs} (MeV ⁻¹) ^{f)}	a_{obs}/a_p
Ti ^{g)}	23	8%			1.93		8.1- ⁴⁷ Ti	6.41- ⁴⁷ Ti	0.79
	24	8%							
	25	73%							
	26	5%							
	27	5%							
V ^{g)}	27	100%			1.96		8.7- ⁵⁰ V	6.35- ⁵¹ V	0.73
Cr	25	4%	P	G	1.89		8.6- ⁵¹ Cr	6.9 - ⁵¹ Cr	<u>0.80</u>
	27	84%							
	28	10%							
	29	2%							
Mn	29	100%	V.P.	G	2.1		8.2- ⁵⁴ Mn	7.82- ⁵⁶ Mn	0.94
Fe	27	6%	F	G	1.96		8.0- ⁵⁵ Fe	7.06- ⁵⁵ Fe	<u>0.88</u>
	29	92%							
	30	2%							
Co	31	100%	P	F	2.12		7.7- ⁵⁸ Co	8.35- ⁶⁰ Co	1.08
Ni ($Z = 28$)	29	68%	V.P.	P	2.04	1.4	6.5- ^{57,7} Ni	7.19- ⁵⁹ Ni	1.10
	31	26%							
	32	1%							
	33	4%							
	35	1%							
Cu	33	69%	V.P.	P	1.78	1.0	9.8- ⁶² Cu	8.90- ⁶⁴ Cu	0.91
	35	31%							
Zn	33	49%	F	F	1.61		10.5- ^{64,4} Zn	10.0- ⁶⁵ Zn	0.95
	35	28%							
	36	4%							
	37	19%							
As	41	100%	V.P.	F	1.44		14.5- ⁷⁴ As	12.81- ⁷⁶ As	0.83
Se ^{g)}	41	9%			1.39		13.3- ⁷⁸ Se	12.8 - ⁷⁸ Se	<u>0.97</u>
	42	8%							
	43	24%							
	45	50%							
	47	9%							
Br	43	45%	V.P.	V.P.	1.41		14.5- ⁷⁹ Br	12.69- ⁸⁰ Br	0.88
	45	49%							
Sr	47	10%	F	G	1.31		13.6- ⁸⁷ Sr	11.4 - ⁸⁷ Sr	<u>0.84</u>
	48	7%							
	49	83%							

^{a)} Neutron numbers and abundances of respective residual nuclei in (γ, n) experiments.

^{b)} These give an assessment of the goodness of fit of a calculated \bar{E}_n versus E_0 curve to the observed data, using the Fermi gas level density formula both without and with pairing corrections.

^{c)} Bremsstrahlung photon-neutron mean energies \bar{E}_n for peak bremsstrahlung energy $E_0 = 24$ MeV.

^{d)} Nuclear temperature from fit with constant-temperature formula.

^{e)} Level density parameter a_p derived from the present (γ, n) experiment, using a Fermi gas formula plus pairing correction, and corresponding residual nucleus (the atomic weight shown is the weighted average of atomic weights of the respective isotopes present).

^{f)} As column 7, but using data on n-resonance absorption from refs. ^{1,2}).

^{g)} Measurements of $\bar{E}_n(E_0)$ for these nuclei were made only for $E_0 = 21, 23$ and 24 MeV.

REF. J. Arends, J. Eyink, A. Hegerath, K.G. Hilger, B. Mecking,
G. Nöldeke, H. Rost
Phys. Lett. 98B, 423 (1981)

ELEM. SYM.	A	Z
Ti		22
REF. NO.		hg
81 Ar 1		

METHOD						REF. NO.		hg
						81 Ar 1		
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE	
			TYPE	RANGE	TYPE	RANGE		
G,MU-T	ABX	215-386	D	215-386	TOF-D		4PI	

DATA ALSO IN 81AR3

Double differential cross sections for the photo-emission of protons and charged pion production were investigated for a number of target nuclei (He, Be, C, O, Al, Ti, Cu, Sn, Pb) in the photon energy range $k = (215-386)$ MeV. On the basis of these experimental results the total hadronic cross section was determined.

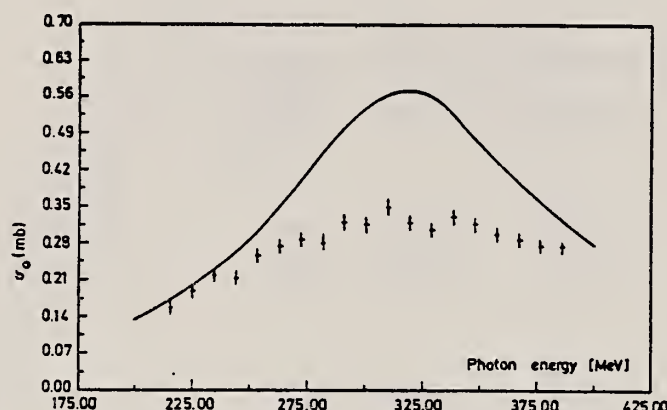


Fig. 7. Parameter σ_0 as a function of photon energy (data points) compared to the mean cross section for a free nucleon (solid line).

The total hadronic cross sections for all measured elements can be parametrized in the form

$$\sigma(k, A) = \sigma_0(k) \cdot A^x,$$

A being the atomic number, with a constant exponent $x = 1.1$. The photon energy dependence of σ_0 is shown in fig. 7. Compared to the mean cross section for a free nucleon (the solid line in fig. 7) the excitation of the Δ -resonance is suppressed. Such a suppression is expected in the Δ -hole model [11].

REF. J. Arends, J. Eyink, A. Hegerath, K.G. Hilger, B. Mecking,
G. Nöldeke, H. Rost
Nucl. Phys. A358, 367c (1981)

ELEM. SYM.	A	Z
Ti		22
REF. NO.		.
81 Ar 3		hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,MU-T	ABX	215-386	D	215-386	TOF-D		4PI

Abstract: Double differential cross sections for the photoemission of protons and charged pion photoproduction were investigated for a number of target nuclei (He, Be, C, O, Al, Ti, Cu, Sn, Pb) using the tagged bremsstrahlung beam at the Bonn 500 MeV-Synchrotron in the photon range $k = (215-386)$ MeV. On the basis of these experimental results the total hadronic cross section was determined.

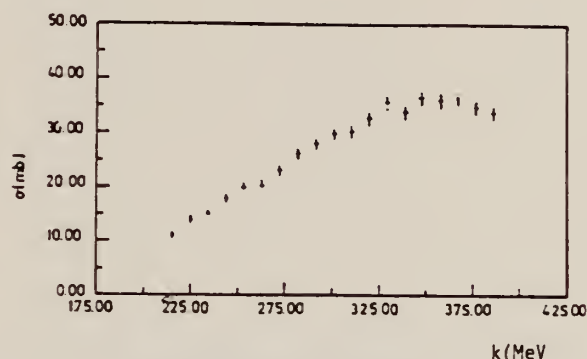


Fig. 2. Cross section for the process: $\gamma + \text{Pb} \rightarrow p + X$.
The proton threshold is 58 MeV.

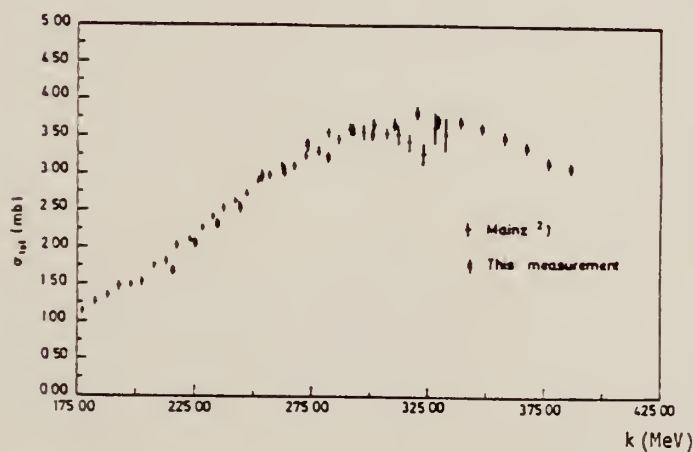


Fig. 3. Total hadronic cross section for Be. The data are compared to the cross section taken from ref.²).

The photon energy dependence of the total cross sections for heavier nuclei are similar to the Be results. The complete data set can be parametrized in the form

$$\sigma(k, A) = \sigma_0(k) \cdot A^x.$$

The exponent is constant $x = 1.1$. The photon energy dependence of σ_0 is shown in fig. 4. Compared to the mean cross section for a free nucleon, the excitation of the Δ -resonance is suppressed.

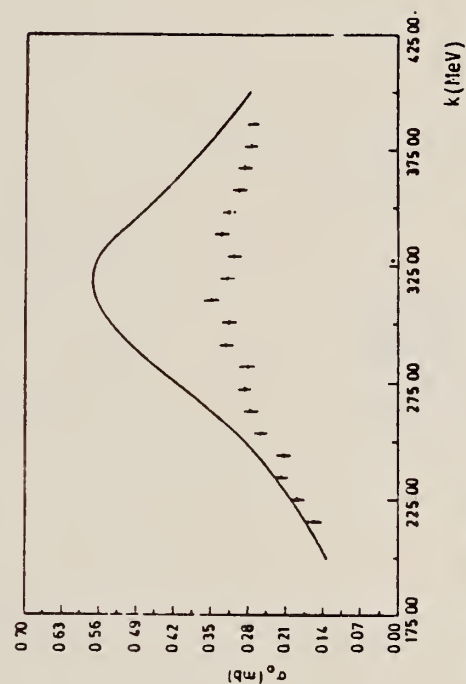


Fig. 4. Parameter σ_0 compared to the cross section for a free nucleon (full line).

$\overline{\text{T}}\text{I}$
A=44

$\overline{\text{T}}\text{I}$
A=44

$\overline{\text{T}}\text{I}$
A=44

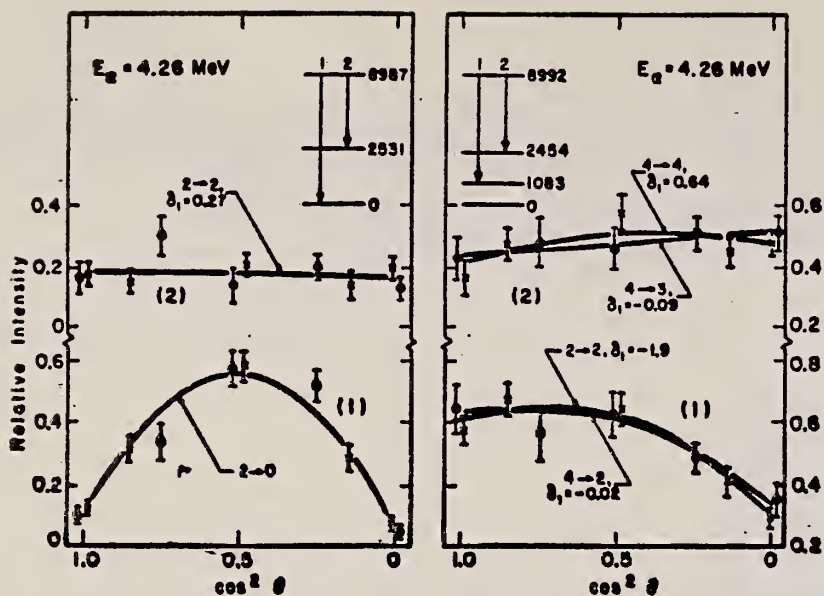


FIG. 7. Angular distributions of primary γ rays from the $E_\alpha = 4.26$ MeV resonance (see caption for Fig. 4).

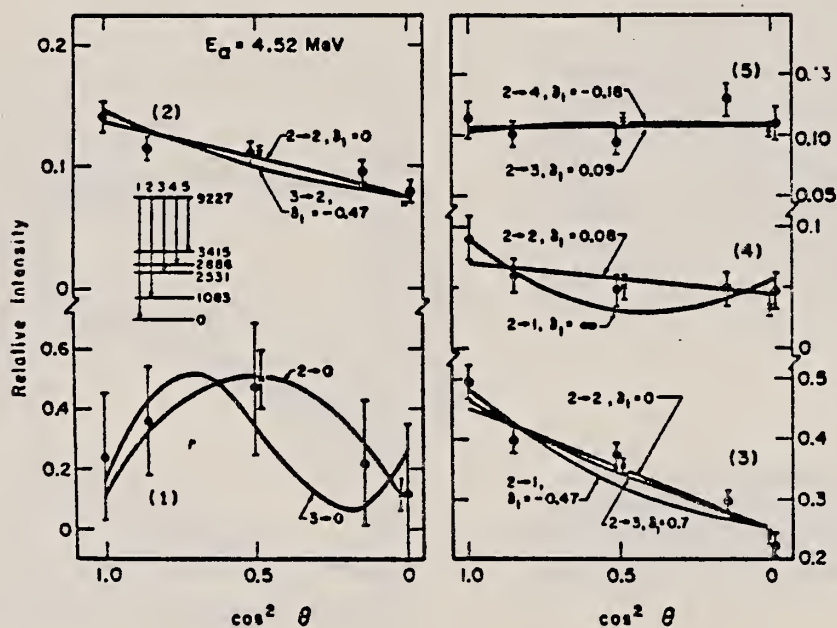


FIG. 11. Angular distributions of primary γ rays from the $E_\alpha = 4.52$ MeV resonance (see caption for Fig. 4).

ELEM. SYM.	A	Z
Ti	44	22
REF. NO.		egf
74 Pe 3		

METHOD				REF. NO.	
				74 Pe 3	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
A.G	ABX	11- 21	D	7- 17	DST

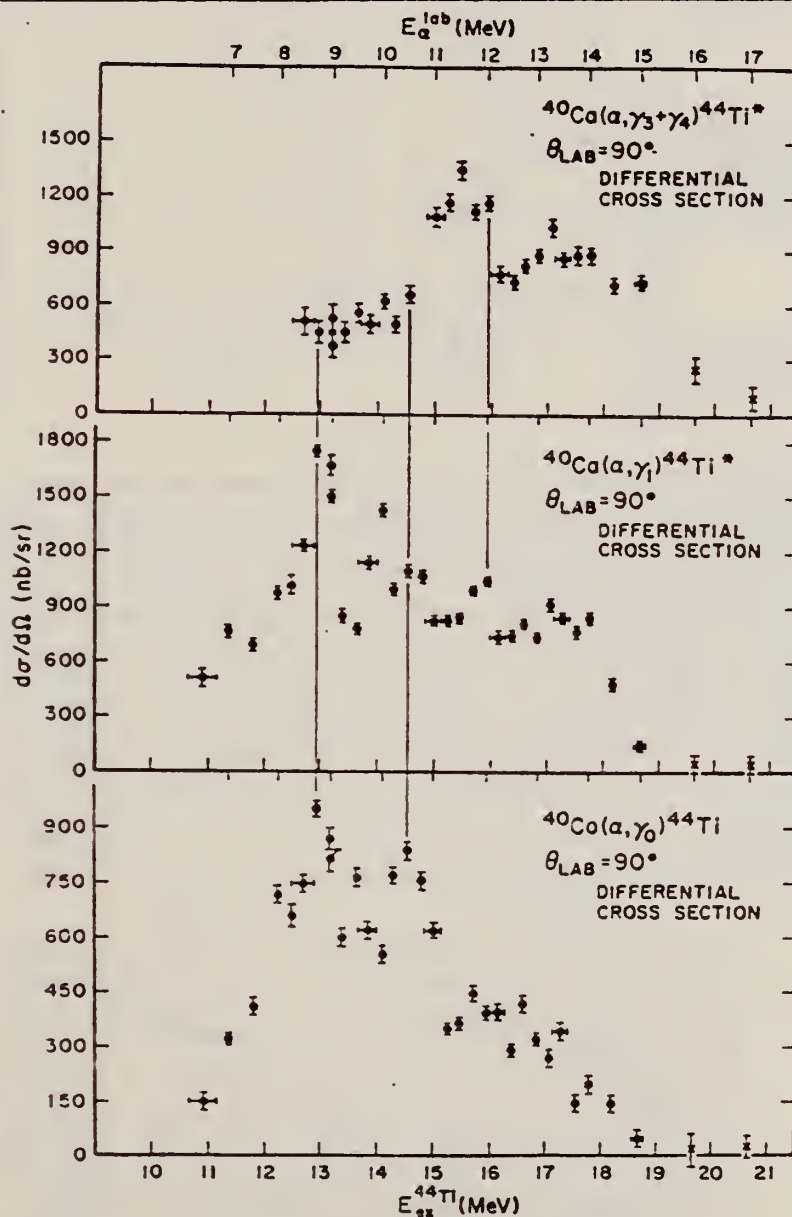


Fig. 3. The 90° differential cross sections for the reactions $^{40}\text{Ca}(\alpha, \gamma_0)$, $^{40}\text{Ca}(\alpha, \gamma_1)$ and $^{40}\text{Ca}(\alpha, \gamma_3 + \gamma_4)$. Points represented by solid dots were obtained with a target 1 mg/cm² thick. Points represented by crosses were obtained with a slightly thicker target. Error bars include only statistical errors.

(over)

$^{40}\text{Ca}(\alpha, \gamma_0)^{44}\text{Ti}$
ANGULAR DISTRIBUTIONS
FITTED WITH $\frac{d\sigma}{d\Omega} = \sum_{n=0}^4 A_n P_n(\cos \theta_{c.m.})$

UNITS ARE ARBITRARY

70

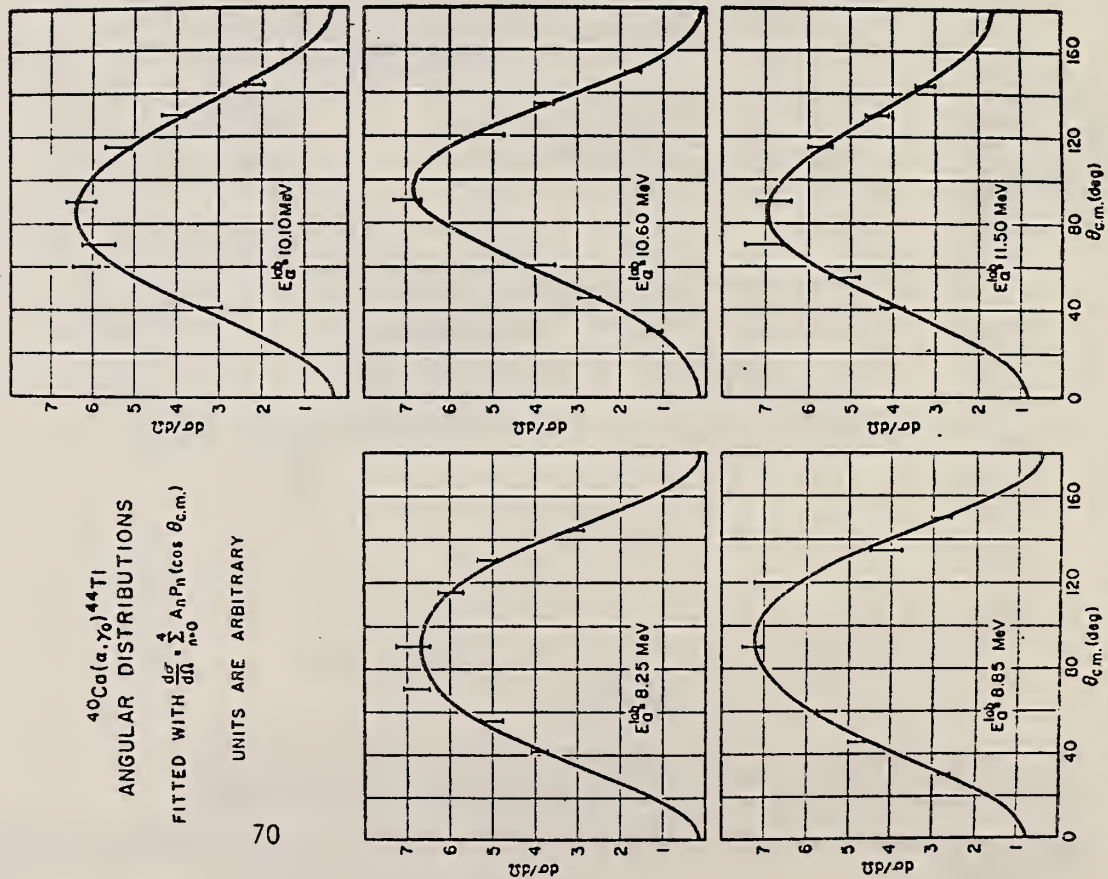


Fig. 4. Angular distributions of the reaction $^{40}\text{Ca}(\alpha, \gamma_0)^{44}\text{Ti}$. Data are shown as bars, the height of which represents the statistical errors. The solid lines are the Legendre polynomial fits.

TABLE I
The E1 and E2 transition strengths extracted from the $^{40}\text{Ca}(\alpha, \gamma_0)$ angular distributions

$E_\alpha^{\text{lab}}(\text{MeV})$	A_2^{exp}	a^2	$(1-a^2)$	A_2^{exp}
8.25	-0.80 ± 0.08	0.88 ± 0.09	0.10 ± 0.04	-0.16 ± 0.07
8.85	-0.77 ± 0.04	0.86 ± 0.05	0.06 ± 0.04	-0.11 ± 0.07
10.10	-0.86 ± 0.10	0.92 ± 0.11	0.03 ± 0.01	-0.057 ± 0.01
10.60	-1.06 ± 0.04	1.03 ± 0.04	0.04 ± 0.05	$+0.06 \pm 0.08$
11.50	-0.73 ± 0.12	0.84 ± 0.13	0.01 ± 0.08	-0.02 ± 0.14

$$d\sigma/d\Omega_{\text{exp}} = (\sigma_T/4\pi)(1 + \sum_{n=1}^4 A_n P_n)$$

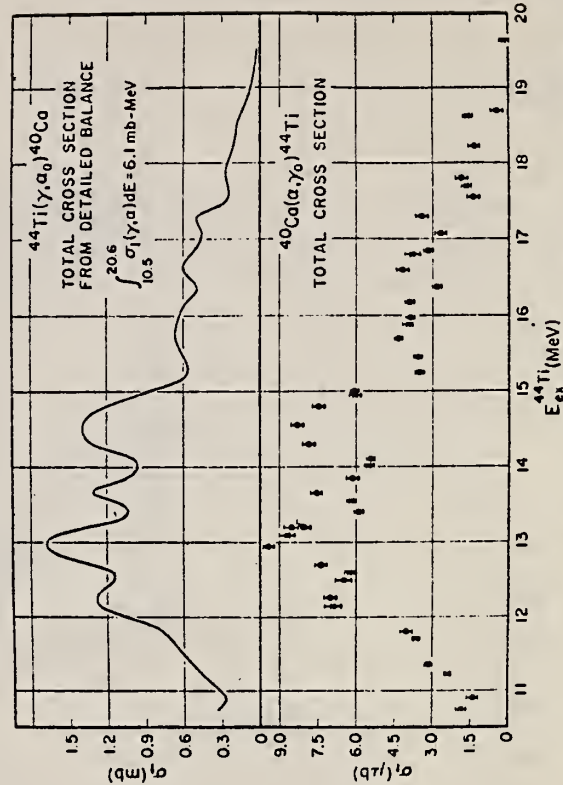


Fig. 7. Total cross section for the reaction $^{40}\text{Ca}(\alpha, \gamma_0)^{44}\text{Ti}$ obtained from the 90° differential cross section by assuming a $\sin^2 \theta$ function for the angular distribution. The points represented by solid dots were obtained with a target 1 mg/cm² thick. The points represented by crosses were obtained with a slightly thicker target. The upper curve is the $^{44}\text{Ti}(\gamma, \alpha_0)^{40}\text{Ca}$ total cross section obtained from detailed balance.

T_I
A=46

T_I
A=46

T_I
A=46

ELEM. SIM.	A	Z
Ti	46	22

METHOD					REF. NO.		NVB	
Betatron					58 Si 4			
REACTION		RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		
				TYPE	RANGE	TYPE	RANGE	ANGLE
G,N		RLX	13-22	C	THR-22	ACT-I		4PI

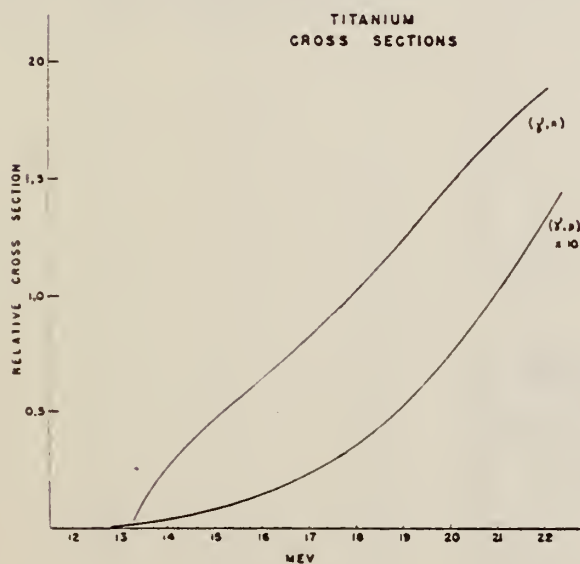


Fig. 4

Elem. Sym.	A	Z
Ti	46	22
Ref. No.	62 Sh 5	
	EGF	

Method
Bremss.; Canberra electron synchrotron; activity

Reaction	E or ΔE
Ti ⁴⁶ (γ, n)	Bremss.
Ti ⁴⁶ (γ, np)	14-31

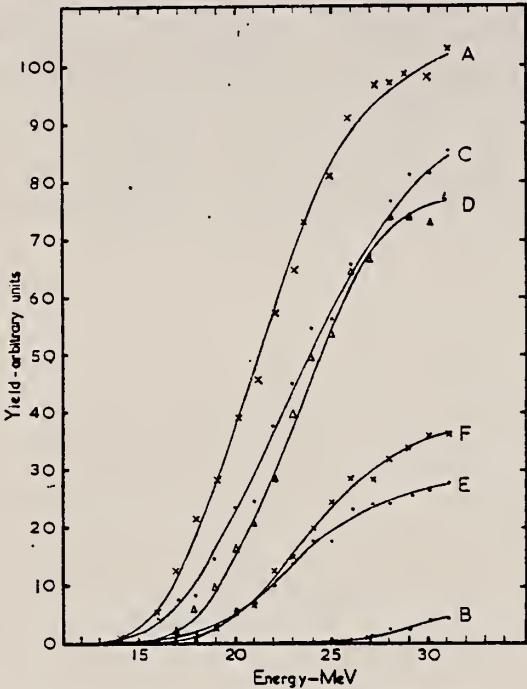


Fig. 1. Activation curves for the photo-disintegration of titanium. A: ⁴⁶Ti; B: ⁴⁴Sc (ground state decay); C: ⁴⁴Sc; D: ⁴⁷Sc; E: ⁴⁸Sc; F: ⁴⁹Sc.

TABLE 4

Comparison of experimental results with statistical theory predictions for gamma rays of 22 MeV

Ratio of cross sections	Experimental	Theoretical
⁴⁷ Ti(γ, p) / ⁴⁸ Ti(γ, p)	0.81	1.40
⁴⁹ Ti(γ, p) / ⁴⁸ Ti(γ, p)		
⁵⁰ Ti(γ, p) / ⁴⁸ Ti(γ, p)	0.39	0.63
⁴⁹ Ti(γ, p) / ⁴⁸ Ti(γ, p)		
⁴⁸ Ti(γ, p) / ⁴⁹ Ti(γ, p)	0.45	0.56
⁴⁸ Ti(γ, p) / ⁴⁹ Ti(γ, p)		
⁴⁹ Ti(γ, p) / ⁴⁸ Ti(γ, p)	0.98	0.34
⁴⁴ Ti(γ, n)		

TABLE 3

Integrated (to 31 MeV) cross sections

Reactions	Relative weights	Integrated cross section (MeV · mb)
⁴⁴ Ti(γ, n) : ⁴⁷ Ti(γ, 2n)	1 : 1.09	260 ± 34
⁴⁴ Ti(γ, np)		
⁴⁷ Ti(γ, p) : ⁴⁸ Ti(γ, np)	1 : 10.1	246 ± 38
⁴⁹ Ti(γ, p) : ⁴⁸ Ti(γ, np)		
⁴⁹ Ti(γ, p) : ⁵⁰ Ti(γ, np)	1 : 0.07	217 ± 32
⁴⁹ Ti(γ, p) : ⁵⁰ Ti(γ, np)		
⁴⁹ Ti(γ, p) : ⁵⁰ Ti(γ, np)	1 : 0.96	86 ± 13
⁵⁰ Ti(γ, p)		
⁵⁰ Ti(γ, p)		113 ± 32

*) Upper limit. The partial cross section from the ⁴⁴Sc formed in the ground state is 4.4 MeV · mb.

Notes

Table 3: Cu⁶³(γ, n) by Berman and Brown [Phys. Rev. 96, 83 (1954)] used as standard.

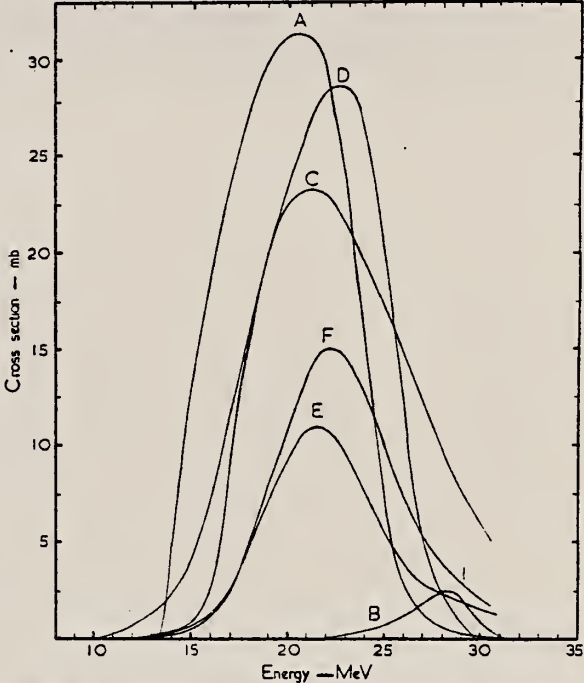


Fig. 2. Excitation function for the photo-disintegration of titanium. A: ⁴⁶Ti(γ, n) + 1.09 ⁴⁷Ti(γ, 2n); B: ⁴⁴Ti(γ, np); C: ⁴⁷Ti(γ, p) + 10.1 ⁴⁸Ti(γ, np); D: ⁴⁸Ti(γ, p) + 0.07 ⁴⁹Ti(γ, np); E: ⁴⁹Ti(γ, p) + 0.96 ⁵⁰Ti(γ, np); F: ⁵⁰Ti(γ, p).

Ref. D.K. Kaipov, R.B. Begzhanov, A.V. Kuz'minov, Yu.K. Shubnyi
 Zhur. Eksp. i Teoret. Fiz. 44, 1811 (1963)
 Soviet Phys. JETP 17, 1217 (1963)

Elem. Sym.	A	Z
Ti	46	22

Method Gaseous radioactive source; resonance scattering; NaI

Ref. No.	JHH
63 Ka 1	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J \pi$	Notes
$Ti^{46}(\gamma, \gamma)$	0.890	0.890				<p>Mean resoance scattering cross section:</p> $\bar{\sigma}(0.890 \text{ MeV}) = (1.91 \pm 0.16) 10^{-26} \text{ cm}^2$ <p>Lifetime:</p> $\tau_{\gamma} = (1.42 \pm 0.20) 10^{-11} \text{ sec.}$ <p>for 0.890 MeV state.</p> <p>Detector at 108°.</p>

ELEM.	STM.	A	Z
Ti	46		22

METHOD					REF. NO.		
Bremsstrahlung from Linac					66 Ta 1		JDM
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,NP	RLY	THR - 48	C	24-48	ACT - I	0-1.4	4PI

Level density $\rho(J) = \rho(0)(2J + 1) \exp \left[-\left(J + \frac{1}{2}\right)^2 / 2\sigma^2 \right]$
Measured relative yield to g.s. and .27 MeV isomer.

TABLE I. Isomer ratios for ^{46}Sc , ground-state yield/total yield $g/(g+m)$.

	Reaction		
	$^{46}\text{Sc}(\gamma, n)$	$^{46}\text{Ti}(\gamma, np)$	$^{46}\text{Sc}(n, 2n)$
Bremsstrahlung endpoint energy (MeV)			
24	0.86 ± 0.02		
36	0.84 ± 0.02		
48	0.84 ± 0.03	> 0.98	
X-radiation energy range (MeV)			
Threshold-24	0.86 ± 0.02		
24-36	0.79 ± 0.13		
36-48	0.84 ± 0.40		
Neutron energy 13.9 MeV			
From measurement of the 1.16-MeV γ line			0.581 ± 0.025
From measurement of the annihilation radiation			0.586 ± 0.010

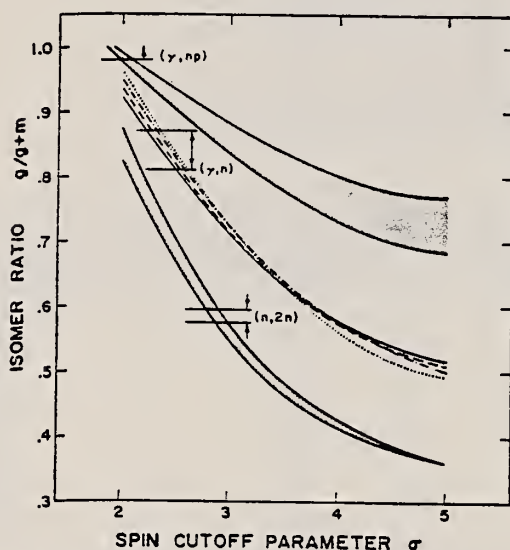


FIG. 6. Calculated isomer ratios versus spin cutoff parameter σ . The top shaded area shows typical calculated results as a function of σ for the (γ, np) reaction. The horizontal line at $g/(g+m) = 0.98$ is the experimental value. The bottom area shows results obtained for the $(n, 2n)$ reaction with the two horizontal lines indicating the experimental result. The middle set of curves are results for the (γ, n) reaction. Each line corresponds to a different assumption which is given in the text.

REF. D. B. Gayther, J. W. McMillan, and H. A. Medicus
 International Conference on Clustering Phenomena in Nuclei.
 Bochum, 21-24 July 1969. International Atomic Energy Agency,
 Vienna, 1969)

ELEM. SYM.	A	Z
Ti	46	22

METHOD	REF. NO.
	69 Ga 2 egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, NP	ABX	30, 34	C	31-39	ACT-I		4PI
G, 2N	ABX	30, 34	C	31-39	ACT-I		4PI

Difference spectra Beamsstrahlung energies (MeV)	$\sigma(\gamma, np)$ (mb)	$\sigma(\gamma, 2n)$ (mb)	$\sigma(\gamma, np)/\sigma(\gamma, 2n)$	
			observed	calculated
31 - 35	1.6 ± 0.2	0.53 ± 0.08	2.9 ± 0.6	1.1
35 - 39	2.3 ± 0.5	0.37 ± 0.08	6.1 ± 1.1	2.2

REF.	J. Heisenberg, J. S. McCarthy and I. Sick Nucl. Phys. <u>A164</u> , 353 (1971)	ELEM. SYM.	A	Z
		Ti	46	22
METHOD		REF. NO.	71 He 1	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1, 2	D	198-300	MAG-D		DST

1=0.885, 2=2.0

TABLE 3
Inelastic parameters

Isotope	E* (MeV)	L	Shape	c _{tr} ^{a)} (fm)	z _{tr} ^{a)} (fm)	G ^{b)} (s.p.u.)	R _{tr} ^{a)} (fm)	G(s.p.u.) heavy-particle scattering ¹⁹⁾
⁴⁰ Ca	3.740	3.	2	3.536±0.030	1.483±0.020	24.9 ±1.0	4.835±0.030	23.6±3.5
	4.480	5	2	3.538±0.050	1.260±0.035	9.7 ±0.6	4.810	17.7±2.7
			3			17.7 ±1.5	5.467±0.060	11.3±1.7
⁴² Ca	3.440	3	2	3.565±0.018	1.383±0.014	12.4 ±0.5	4.719±0.023	12.0±1.8
	4.100	5	2	3.231±0.030	1.404±0.025	3.4 ±0.3	4.816±0.044	9.0±1.4
⁴⁴ Ca	3.30	3	2	3.555±0.018	1.313±0.013	6.95±0.28	4.618±0.023	8.0±1.2
	2.28	4	2	4.091±0.030	1.268±0.016	2.66±0.15	5.135±0.030	1.3±0.3
	3.91	5	2	3.268±0.030	1.397±0.024	2.30±0.20	4.832±0.045	4.4±0.7
⁴⁶ Ti	2.00	4	2	4.264±0.021	1.229±0.013	7.61±0.30	5.226±0.026	
⁴⁸ Ti	2.286	4	2	4.330±0.021	1.196±0.013	3.37±0.15	5.237±0.026	
⁵⁰ Ti	4.42	3	2	3.645±0.017	1.244±0.012	3.76±0.15	4.600±0.023	5.4±0.8
								5.9 ²⁰⁾
	2.50	4	2	3.865±0.017	1.347±0.012	4.7 ±0.15	5.064±0.026	3.3±0.7
	3.20	5	2	3.254±0.032	1.345±0.026	0.83±0.08	4.724±0.045	2.7 ²⁰⁾

Present experiment

^{a)} Errors do not reflect any model dependence.

^{b)} Given errors do not include the 6% error of normalization.

¹⁹⁾ A. M. Bernstein, Adv. in Nucl. Phys. 3 (1969) 325.

- 13) J. Simpson, J. Cookson, D. Eccleshall and M. Yates, Nucl. Phys. 62 (1965) 385
 14) G. M. Temmer and N. P. Heydenburg, Phys. Rev. 104 (1956) 967
 15) D. S. Andreyev, A. P. Grinberg, K. I. Erokhina and I. Kh. Lemberg, Nucl. Phys. 19 (1960) 400
 16) F. R. Metzger, Nucl. Phys. 27 (1961) 612
 17) W. H. Kelly and G. B. Beard, Nucl. Phys. 27 (1961) 188
 18) R. B. Begzhanov, A. A. Islamov, D. K. Kaipov and Yu. K. Shubnyi, JETP (Sov. Phys.) 17 (1963) 94

[over]

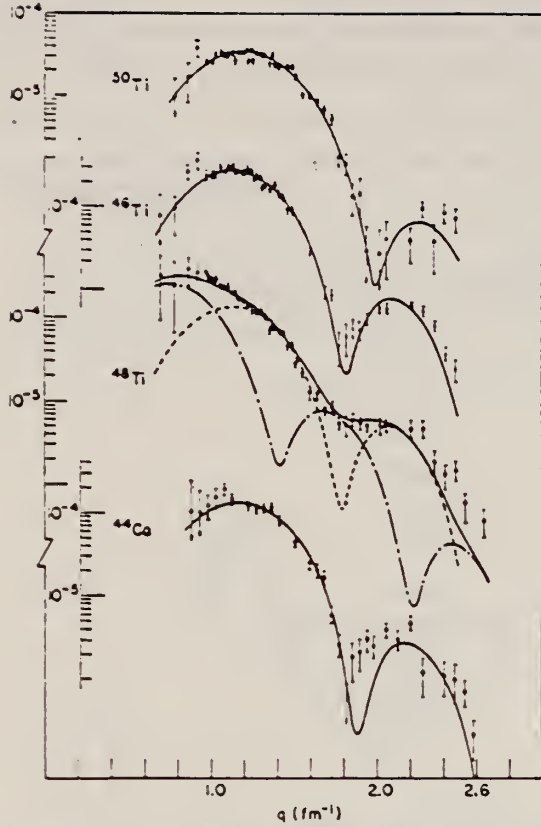


Fig. 6. Fits to ^{40}Ti , ^{46}Ti , ^{48}Ti and ^{44}Ca 4^+ levels. For ^{48}Ti we show the decomposition into contributions of the 2.42 MeV 2^+ level (dash-dot curve) and the 2.286 MeV 4^+ level (dashed curve).

TABLE 2
Inelastic parameters for 2^+ levels

Isotope	E^* (MeV)	$B(E2)$ Coulomb Excit: ($e^2 \cdot \text{fm}^4$)	Shape	r_{tr}^a (fm)	r_{tr}^b (fm)	Fitted $B(E2)$ ($e^2 \cdot \text{fm}^4$) ^b	R_{tr}^c (fm)	$B(E2)(e^2 \cdot \text{fm}^4)$ heavy-particle scattering
^{42}Ca	1.520	364 ± 82 ^{a)}	2	1.459 ± 0.020		320 ± 20	4.619 ± 0.030	476 ± 74 ¹⁹⁾
^{44}Ca	1.160	350 ± 70 ¹⁹⁾	2	1.428 ± 0.020		480 ± 30	4.704 ± 0.030	507 ± 100 ¹⁹⁾
			1	0.690 ± 0.010		1270 ± 85	5.553 ± 0.030	
^{46}Ti	3.259		2			54 ± 10		
	0.885	830 ± 170 ¹⁴⁾	2	1.397 ± 0.010		740 ± 20	4.763 ± 0.017	867 ²⁰⁾
		560 ± 100 ¹⁵⁾	1	0.669 ± 0.005		1680 ± 50	5.510 ± 0.020	738 ¹¹⁾
^{48}Ti	0.984	700 ± 140 ¹⁴⁾	2	1.340 ± 0.010		537 ± 15	4.671 ± 0.017	788 ± 120 ¹⁹⁾
		310 ± 70 ¹⁵⁾	1	0.633 ± 0.005		1110 ± 30	5.321 ± 0.020	673 ¹¹⁾
								659 ²⁰⁾
^{50}Ti	2.420		2			49 ± 8		57 ± 10 ¹⁹⁾
	1.580	240 ± 20 ¹⁵⁾	2	1.255 ± 0.010		307 ± 10	4.567 ± 0.017	349 ²⁰⁾
			1	0.576 ± 0.005		515 ± 17	5.047 ± 0.020	260 ²¹⁾
								431 ²²⁾
^{56}Fe	4.320		2			51 ± 8		72 ²³⁾
	0.880	877 ± 70 ⁹⁾	2	1.357 ± 0.014		945 ± 45	4.919 ± 0.025	
			1	0.651 ± 0.006		1570 ± 70	5.454 ± 0.030	
Present experiment								

^{a)} Errors do not reflect any model dependence.

^{b)} Given errors do not include the 6% error of normalization.

^{c)} Average for $B(E2)$ formed from values of refs. ¹³⁻¹⁹⁾.

METHOD

REF. NO.

76 Ra 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	3, 4	C	1- 5	SCD-D		DST
		(3.168,4.316)		(1.3-4.7)			

3168,4316 KEV

TABLE II. Mean lives of some levels in the titanium isotopes.

Mass no., ground state, spin, & abund.	Level energy (keV)	Level spin	Γ_0 (meV)	τ (pres. meas.) (fs)	τ (other) (fs)
46, 0 ⁺ 7.95%	3168	1 ⁻	7.3±2.0	41±12	71±12 ^a
	4316	1	(172±26)Γ/Γ ₀	0.96±0.14 ^b	<44 ^a
47, $\frac{3}{2}^{-}$ 7.75%	2162	$\frac{3}{2}^{-}$	18±5	38±10	31±8 ^c
	2297	($\frac{5}{2}^{-}, \frac{1}{2}^{-}$)	{ 104±10 or ^d 78±8	4.7±0.5 or ^d 6.3±0.7	11±7 ^c
	2548	$\frac{3}{2}^{-}$	72±8	9±1	
48, 0 ⁺ 73.45%	2421	2 $\frac{1}{2}^{+}$	0.74±0.18	44±12	35±7 ^e
					{ Γ ₀ =0.66±0.11 meV and 0.77±0.14 ^f
	3371	2 $\frac{3}{2}^{+}$	5.5±0.6	16.1±2.1	18±7 ^e
	3700	1 ⁽⁺⁾	20.4±2.3	15.1±1.6	35±3 ^g
	3739	1 ⁺	101±10	4.2±0.4	16±3 ^g
49, $\frac{1}{2}^{-}$ 5.51%	1623	($\frac{3}{2}^{-}, \frac{5}{2}^{-}, \frac{1}{2}^{-}$)	11.4±1.5 ^h	55±7	
	1763	$\frac{3}{2}^{-}$	18.3±2.2	36±4.3	
50, 0 ⁺ 5.34%	1554	2 $\frac{1}{2}^{+}$	0.52±0.15	1300±400	Γ=0.18±0.04 meV ⁱ
	(4311)	2 ⁺	85±60	1<τ<6	<80 ^j
(47, 49)	3917		(90±20)Γ/gΓ ₀ ^k		
	2810		(29±4)Γ/gΓ ₀ ^k		

^a Reference 11.

^b Assuming Γ₀/Γ=0.50.

^c Reference 18.

^d The larger width and shorter lifetime correspond to spin $\frac{5}{2}$.

^e Reference 23.

^f Coulomb excitation and (e, e'), J. Heisenberg, J. S. McCarthy, and I. Sick, Nucl. Phys. A164, 353 (1971).

^g C. D. Kavaloski and W. J. Kossler, Phys. Rev. 180, 971 (1969).

^h Assuming spin $\frac{3}{2}$.

ⁱ From Coulomb excitation results of C. W. Towsley, D. Cline, and R. Horoshko, Nucl. Phys. A250, 381 (1975).

^j Reference 12.

^k Calculated as if ⁴⁸Ti, g is the statistical factor.

¹¹ P.A. Assimakopoulos et al., Nucl. Phys. A180, 131 (1972).

¹² J.G. Pronko et al., Phys. Rev. C10, 1345 (1974).

¹⁸ J.J. Weaver et al., Nucl. Phys. A196, 269 (1972).

²³ T.T. Bardin et al., Phys. Rev. C7, 190 (1973).

METHOD

REF. NO.

77 01 1

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,P	ABX	13-25	D	13-25	MAG-D		90
E,A	ABY	12-19	D	12-19	MAG-D		90

Abstract: The cross sections of the $(e, e'p)$ reaction on ^{42}Ca , ^{45}Sc and ^{46}Ti have been measured and used to deduce (γ, p) cross sections. Together with (γ, n) cross sections from others, these data allow an estimate of the T_1 and T_2 GDR cross sections. The experimental results seem to be consistent with the theory on the isospin splitting. The (γ, p_0) or $(\gamma, p_0 + p_1)$ and (γ, x_0) cross sections have also been measured. The ratio $\sigma(\gamma, p_0)/\sigma(\gamma, p)$ indicates a contribution of a statistical nature in the T_1 GDR region and some additional direct modes in the T_2 GDR region. The contribution of one (^{45}Sc) or two (^{46}Ti) extra protons is discussed and it is found that the valence nucleons contribute to GDR in an independent way.

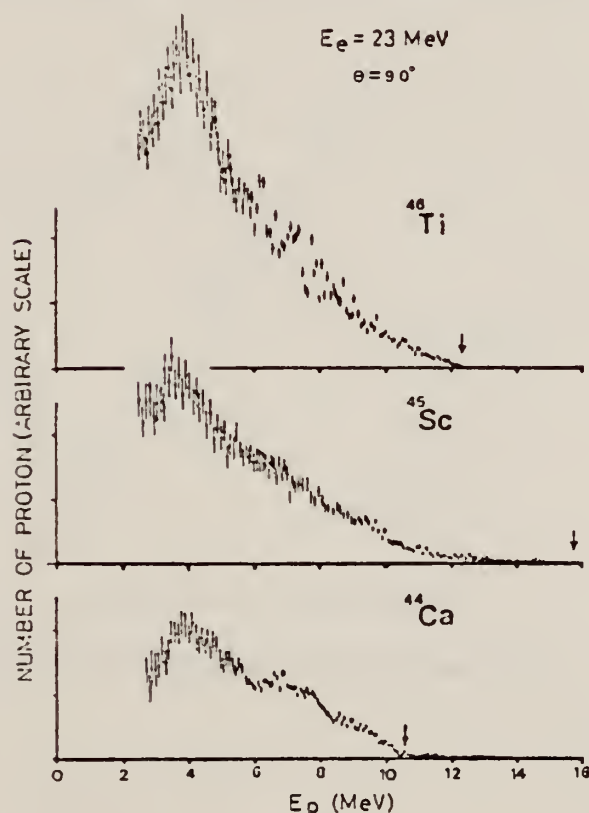


Fig. 4. Example of proton energy distribution obtained with 23 MeV electron beam. Arrows show the proton end point energy.

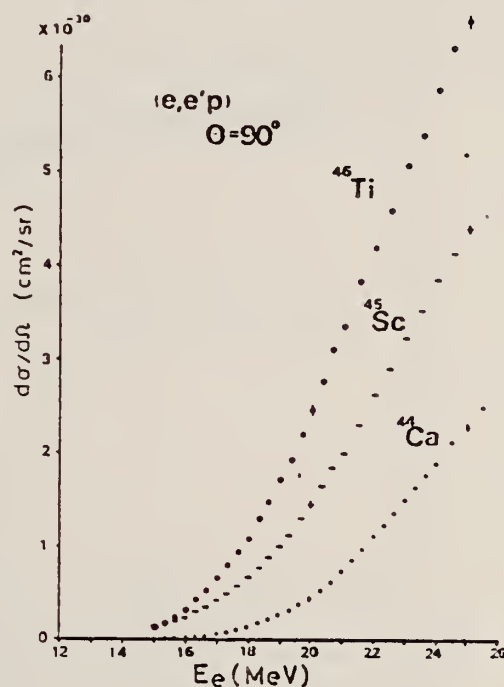


Fig. 5. The differential cross sections at $\theta = 90^\circ$ of the $(e, e'p)$ reaction.

(over)

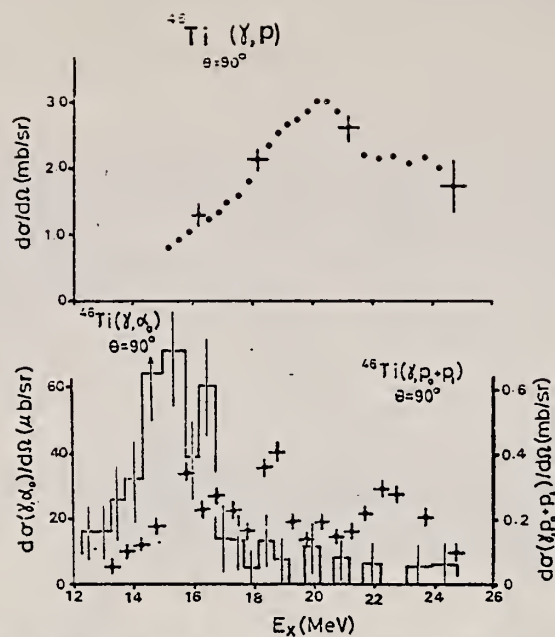


Fig. 8. The differential cross sections at $\theta = 90^\circ$ of the (γ, p) , $(\gamma, p_0 + p_1)$ and (γ, α_0) reactions of ^{46}Ti .

ELEM. SYM.	A	Z
Ti	46	22
REF. NO.		hg
78 Ma 10		

METHOD		REF. NO.		hg	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,N	ABY	13-68	C	30-68	4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

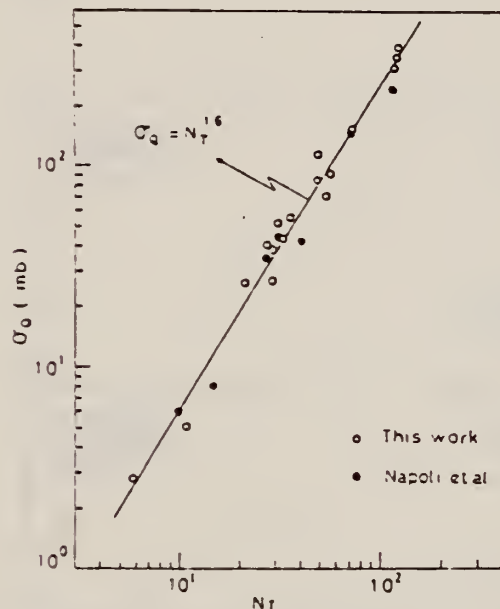


Fig. 2. Yield per equivalent quanta versus target neutron number.

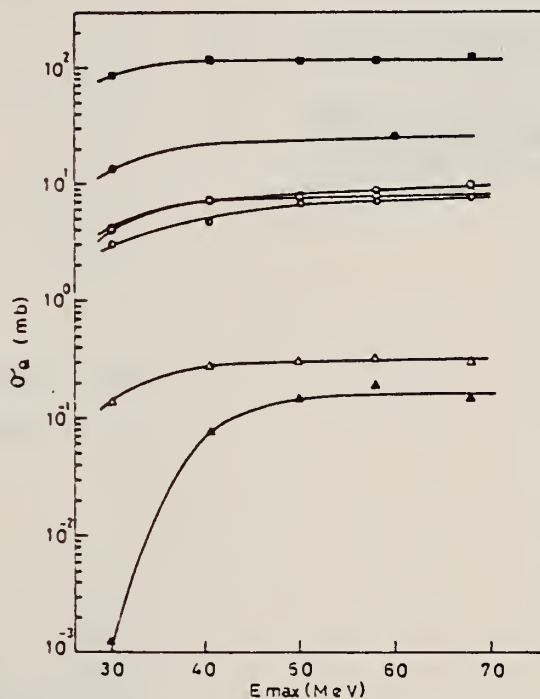


Fig. 4. Activation yield curves for the reactions on Ca, Ti and V.

■ $^{48}\text{Ca}(\gamma, n)^{47}\text{Ca}$, □ $^{44}\text{Ca}(\gamma, p)^{43}\text{K}$, ● $^{46}\text{Ti}(\gamma, n)^{45}\text{Ti}$,
 ○ $^{48}\text{Ti}(\gamma, p)^{47}\text{Sc}$, ◐ $^{49}\text{Ti}(\gamma, p)^{48}\text{Sc}$, △ $^{51}\text{V}(\gamma, \alpha)^{47}\text{Sc}$,
 ▲ $^{51}\text{V}(\gamma, xn)^{40}\text{Sc}$.

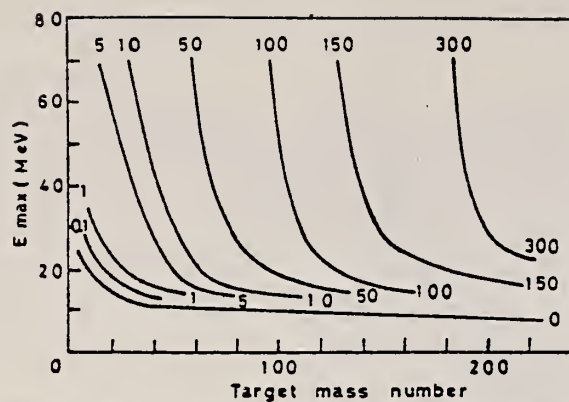


Fig. 9. Yields of the (γ, n) reactions as a function of bremsstrahlung maximum energy and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

ELEM. SYM.	A	Z
Ti	46	22
REF. NO.		hg
79 Py 5		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G,N	ABX	12-25	C	12-26	ACT-I		4 PI

Abstract: The photoneutron cross section, $^{46}\text{Ti}(\gamma, n)$, has been studied in the photon energy range 12 to 25 MeV. Comparison of this cross section with the $^{46}\text{Ti}(\gamma, p)$ cross section shows evidence for isospin splitting of the giant dipole resonance. A detailed calculation for the (γ, n) and (γ, p) cross sections assuming a statistical decay process and taking into account the isospin selection rules and the predictions of Goulard and Fallieros for the energy separation and relative strengths of the two isospin components of the giant dipole resonance, agrees with the experimental results. The possibility of deformation splitting of the ^{46}Ti GDR is also discussed.

MIXED YIELDS MEASURED

COMMENTS

- (1) Absolute scale of the yield curve normalized to that of the $^{63}\text{Cu}(\gamma, n)$ reaction reported in ref. 7,8.
Ref. 7 -- F. Dreyer, H. Dahmere, J. Staude and H.H. Thies, Nucl. Phys. A192 (1972) 433
Ref. 8 -- R.E. Sund, M.P. Baker, L.A. Kull and R.B. Walton, Phys. Rev. 176 (1968) 1366
- (2) Integrated cross section to 25 MeV is 194 ± 40 MeV mb.
- (3) Actual cross section measured is $\sigma(^{46}\text{Ti}(\gamma, n)) + 1.09\sigma(^{47}\text{Ti}(\gamma, 2n)) + 1.36\sigma(^{46}\text{Ti}(\gamma, np))$.

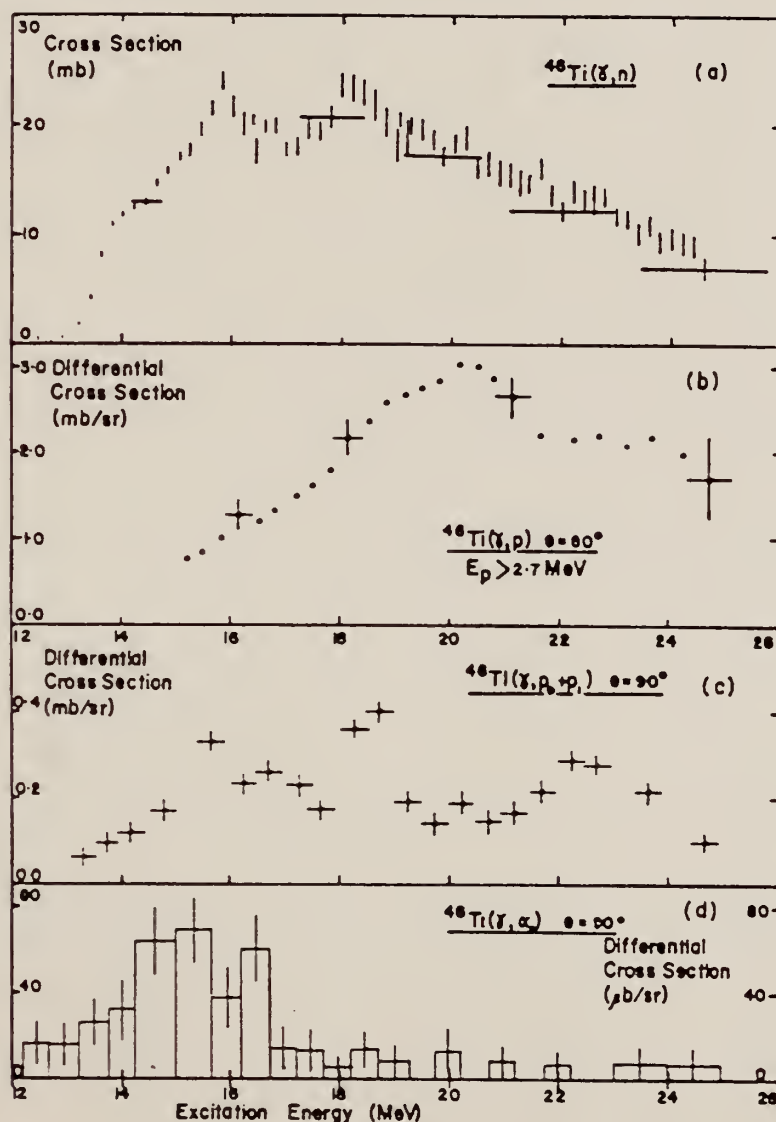


Fig. 2. (a) The $^{46}\text{Ti}(\gamma, n)$ cross section. Vertical error bars show statistical errors only. There is a 20 % uncertainty in the absolute cross section scale. Horizontal bars show the analysis bin width used. (b) The $^{46}\text{Ti}(\gamma, p)$. (c) The $^{46}\text{Ti}(\gamma, p_0 + p_1)$. (d) The $^{46}\text{Ti}(\gamma, \alpha)$ differential cross sections of ref. 5).

Ref. 5 -- S. Oikawa & K. Shoda, Nucl. Phys. A277 (1977) 301

\overline{T}_I
A=47

\overline{T}_I
A=47

\overline{T}_I
A=47

Elem. Sym.	A	Z
Ti	47	22
Ref. No.	62 Sh 5	
	EGF	

Method Bremss.; Canberra electron synchrotron; activity

Reaction	E or ΔE
$\text{Ti}^{47}(\gamma, p)$	Bremss.
$\text{Ti}^{47}(\gamma, 2n)$	14-31

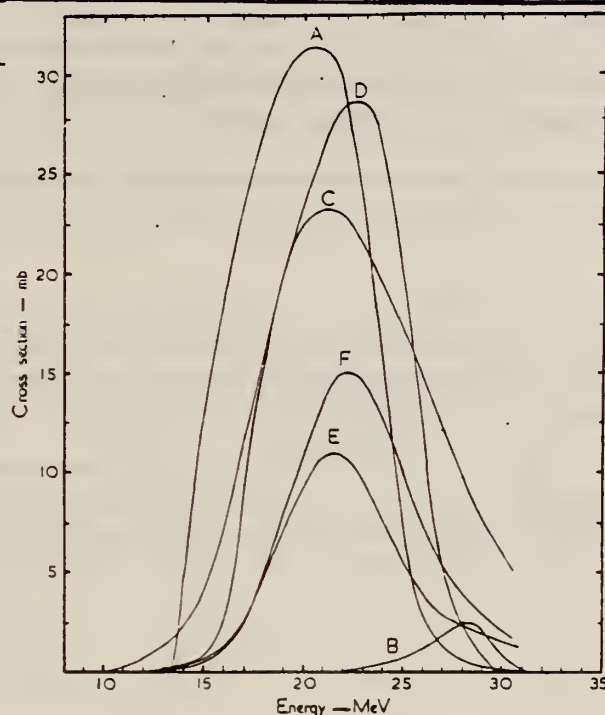


Fig. 2. Excitation function for the photo-disintegration of titanium. A: $^{46}\text{Ti}(\gamma, n) + 1.09$ $^{47}\text{Ti}(\gamma, 2n)$; B: $^{46}\text{Ti}(\gamma, np)$; C: $^{47}\text{Ti}(\gamma, p) + 10.1$ $^{48}\text{Ti}(\gamma, np)$; D: $^{46}\text{Ti}(\gamma, p) + 0.07$ $^{48}\text{Ti}(\gamma, np)$; E: $^{46}\text{Ti}(\gamma, p) + 0.96$ $^{47}\text{Ti}(\gamma, np)$; F: $^{50}\text{Ti}(\gamma, p)$.

TABLE 3
Integrated (to 31 MeV) cross sections

Reactions	Relative weights	Integrated cross section (MeV · mb)
$^{46}\text{Ti}(\gamma, n) : ^{47}\text{Ti}(\gamma, 2n)$	1 : 1.09	260 ± 34
$^{46}\text{Ti}(\gamma, np)$		8.8 ± 1.4 *)
$^{47}\text{Ti}(\gamma, p) : ^{48}\text{Ti}(\gamma, np)$	1 : 10.1	246 ± 38
$^{48}\text{Ti}(\gamma, p) : ^{49}\text{Ti}(\gamma, np)$	1 : 0.07	217 ± 32
$^{49}\text{Ti}(\gamma, p) : ^{50}\text{Ti}(\gamma, np)$	1 : 0.96	86 ± 13
$^{50}\text{Ti}(\gamma, p)$		113 ± 32

*) Upper limit. The partial cross section from the ^{48}Sc formed in the ground state is $4.4 \text{ MeV} \cdot \text{mb}$.

TABLE 4

Comparison of experimental results with statistical theory predictions for gamma rays of 22 MeV

Ratio of cross sections	Experimental	Theoretical
$\frac{^{47}\text{Ti}(\gamma, p)}{^{48}\text{Ti}(\gamma, p)}$	0.31	1.40
$\frac{^{48}\text{Ti}(\gamma, p)}{^{49}\text{Ti}(\gamma, p)}$	0.39	0.63
$\frac{^{49}\text{Ti}(\gamma, p)}{^{50}\text{Ti}(\gamma, p)}$	0.45	0.56
$\frac{^{48}\text{Ti}(\gamma, p)}{^{49}\text{Ti}(\gamma, p)}$	0.93	0.34
$\frac{^{49}\text{Ti}(\gamma, p)}{^{47}\text{Ti}(\gamma, n)}$		

Notes

Table 3: $\text{Cu}^{63}(\gamma, n)$ by Berman and Brown [Phys. Rev. 96, 83 (1954)] used as standard.

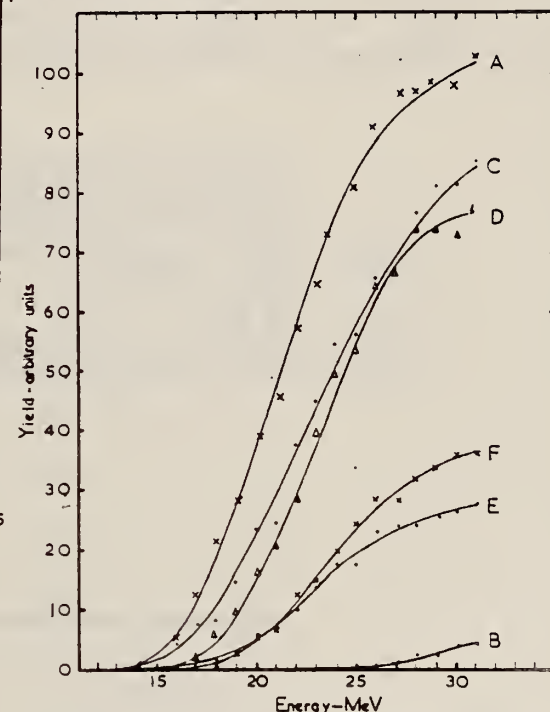


Fig. 1. Activation curves for the photo-disintegration of titanium. A: ^{46}Ti ; B: ^{46}Sc (ground state decay); C: ^{48}Sc ; D: ^{47}Sc ; E: ^{48}Sc ; F: ^{46}Sc .

REF. E. C. Booth, B. Chasan and K. A. Wright
Nuc1. Phys. 57, 403-420 (1964)

ELEM. SYM.	A	Z
Ti	47	22
REF. NO.		
64 Bo 1		NVB

METHOD
Van de Graaff; resonance fluorescence

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G.G	LFT	1-3	C	1 - 3	NAI-D		100
		(0.5 - 3.0)		(0.5 - 3.0)			

ABI

TABLE I
Cases of observed resonance fluorescence

Nucleus multipol.	State (MeV)	Spin	Γ_0/Γ	$T(gw\Gamma_0^2/\Gamma^2)^{-1}$ (sec).	Mean lifetime T BCW (sec)	Mean lifetime T other (sec)	Ref.	Γ_0/Γ_w BCW
Ti ⁴⁷	0.00	$\frac{1}{2}^-$						
[M1] ⁺	2.58	$[\frac{3}{2}^-]$	?	$45^{+20}_{-15} \times 10^{-16}$				$1.0\Gamma/\Gamma_0$

METHOD

[Page 1 of 2]

REF. NO.

67 Pa 2

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	RLY	THR-30	C	22,30	ACT-I		4PI
G,NP	RLY	THR-30	C	22,30	ACT-I		4PI

TABLE I

Yields, Y , and cross sections, σ , of the proton reactions in Ti isotopes excited by photons or neutrons. (The yields and cross sections with primes are "first proton" yields and cross sections)

Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 22 \text{ MeV}$				$E_n = 13 \text{ MeV}$		
		Y_{TP}	Y_{TPa}	Y_{TPb}	Y_{TP}' (cols. 1 + 2)	σ_{TP}	σ_{TPa}	σ_{TP}' (cols. 5 + 6)
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	57	(<1) ^a	(<1)	~57	277	(<10)	~280
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	20	E.I. ^b	E.I.	20	121	34	155
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	9.2	<0.1	<0.1	9.2	69	<1	~70
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	9.6	E.I.	E.I.	9.6	29	<1	~30
Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 30 \text{ MeV}$				$E_n = 19 \text{ MeV}$		
		Y_{TP}	Y_{TPa}	Y_{TPb}	Y_{TP}'	σ_{TP}	σ_{TPa}	σ_{TP}'
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	5.5	(0.03)	(0.04)	5.5	167	47	214
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	2.5	0.24	0.41	2.7	77	70	147
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	1.5	0.29	0.57	1.8	42	31	73
$^{48}\text{Ti}^a$	^{48}Ti ^{46}Ti	1.6	0.17	0.37	1.8	28	9	37

^aBracketed values are calculated from yields for production of ^{48}Ti , as ^{48}Sc is stable.
^bE.I. = energetically impossible.

REF. H. L. Pai and K. G. McNeill Can. J. Phys. <u>45</u> , 3235 (1967)			ELEM. SYM.		A	Z	
			Ti		47	22	
METHOD			REF. NO.				
			[Page 2 of 2] 67 Pa 2			EGF	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

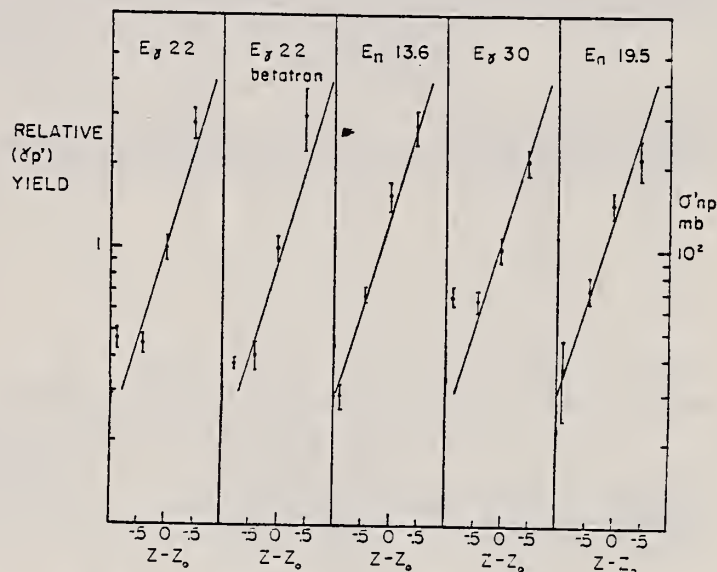


FIG. 1. The relative yields of the first-proton photoreactions in four Ti isotopes plotted as a function of $Z - Z_0$, where $Z = 22$ and Z_0 is the value of Z which minimizes $M(A, Z)$. For ^{46}Ti , $Z - Z_0 = -0.88$, and for ^{48}Ti , ^{49}Ti , and ^{50}Ti the values of $Z - Z_0$ are -0.44 , $+0.01$, and $+0.46$ respectively. Three plots are shown, one obtained at 22 MeV using the linac, one at 30 MeV with the linac, and one at 22 MeV with the betatron. Also shown are cross sections of the first-proton reactions induced by fast neutrons, of energies 13.6 and 19.5 MeV, in Ti isotopes (Pai 1966).

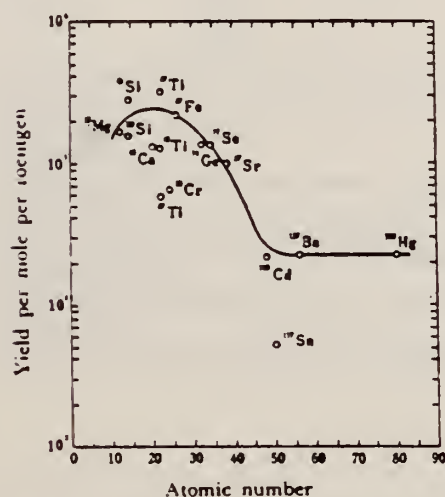
ELEM. SYM.	A	Z
Ti	47	22
REF. NO.		egf
68 Ok 3		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	ABY	THR-20	C	20	ACT-I		4PI

TABLE I. SUMMARY OF DATA ON (γ ,p) REACTIONS WITH 20 MeV BREMSSTRAHLUNG

Nuclide		S_p (MeV)	Observed γ -ray			Yield determined	
Parent (Natural abundance, %)	Residual (Half-life)		Energy (MeV)	Branching ratio (%)	Type of multipole transition	$\mu\text{Ci/mg}^a$	Yield/mol \cdot R
^{23}Mg (10.11)	^{24}Na (15 hr)	12.06	1.37	100	E2	1.48×10^{-1}	1.7×10^3
^{28}Si (4.71)	^{29}Al (2.27 min)	12.33	1.78	100	E2	1.91	2.8×10^3
^{30}Si (3.12)	^{31}Al (6.56 min)	13.59	1.28	93.8	E2+M1	6.51×10^{-1}	1.5×10^3
^{40}Ca (2.06)	^{41}K (22.4 hr)	12.17	0.374	85	E2+M1	7.86×10^{-2}	1.3×10^3
^{47}Ti (7.32)	^{48}Sc (84.1 d)	10.47	0.887	100	E2	7.11×10^{-4}	3.1×10^3
^{48}Ti (73.99)	^{49}Sc (3.4 d)	11.44	0.160	100	E2+M1	6.83×10^{-2}	1.2×10^3
^{49}Ti (5.46)	^{48}Sc (1.8 d)	11.35	1.31	100	E2	4.40×10^{-3}	5.8×10^4
^{52}Cr (9.55)	^{52}V (3.8 min)	11.15	1.43	100	E2	5.01×10^{-1}	6.6×10^4
^{54}Fe (2.17)	^{55}Mn (2.58 hr)	10.57	1.81	23.5	E2+M1	8.10×10^{-2}	2.1×10^3
^{76}Ge (36.74)	^{75}Ga (4.8 hr)	10.92	0.295	97	(E2)	3.70×10^{-1}	1.3×10^3
^{77}Se (7.58)	^{76}As (26.5 hr)	9.61	0.559	41	E2	1.48×10^{-2}	1.3×10^3
^{87}Sr (7.02)	^{86}Rb (19 d)	9.41	1.08	9	E2	5.15×10^{-4}	9.9×10^4
^{111}Cd (12.26)	^{112}Ag (3.2 hr)	9.74	1.39	35	E2	1.91×10^{-2}	2.1×10^4
^{117}Sn (7.57)	^{116}In (54 min)	9.58	1.27	84	E2	9.80×10^{-3}	6.9×10^3
^{137}Ba (11.32)	^{136}Cs (13 d)	8.67	0.830	100	E2	1.68×10^{-4}	2.2×10^4
^{198}Hg (16.84)	^{199}Au (2.7 d)	7.27	0.412	100	E2	8.43×10^{-4}	2.2×10^4

a) The value corrected at the end of 1 hr irradiation (9.4×10^4 R/min).Fig. 2. The yield curve for the (γ ,p) reaction with 20 MeV bremsstrahlung.

METHOD

REF. NO.

69 Ok 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	RLY	THR-60	C	30-60	NAI-D		4PI

YLD REL 12C(G,N)

TABLE 6. THE RELATIVE YIELDS FOR (γ , p) REACTIONS ON TITANIUM
NUCLEI EXPRESSED AS THOSE PER MOLE

Reaction	Yield per mole relative to $^{12}\text{C}(\gamma, n)^{11}\text{C}$			
	30 MeV	45 MeV	55 MeV	60 MeV
$^{48}\text{Ti}(\gamma, p)^{48}\text{Sc}$	5.4×10^{-1}	5.8×10^{-1}	5.4×10^{-1}	6.3×10^{-1}
$^{46}\text{Ti}(\gamma, p)^{46}\text{Sc}$	2.0×10^{-1}	2.4×10^{-1}	2.8×10^{-1}	2.8×10^{-1}
$^{44}\text{Ti}(\gamma, p)^{44}\text{Sc}$	1.2×10^{-1}	2.1×10^{-1}	2.2×10^{-1}	2.1×10^{-1}

REF. V. K. Rasmussen
Phys. Rev. C13, 631 (1976)

ELEM. SYM.	A	Z
Ti	47	22

METHOD

REF. NO.	
76 Ra 1	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	2, 2	C	1- 5	SCD-D		DST
		(2.162, 2.297)		(1.3-4.7)			

2162, 2297, 2548 KEV

TABLE II. Mean lives of some levels in the titanium isotopes.

Mass no., ground state, spin, & abund.	Level energy (keV)	Level spin	Γ_0 (meV)	τ (pres. meas.) (fs)	τ (other) (fs)
46, 0 ⁺ 7.95%	3168 4316	1 ⁻ 1	7.3 = 2.0 (172 = 26) Γ/Γ_0	41 ± 12 0.96 ± 0.14 ^b	71 ± 12 ^a < 44 ^a
47, $\frac{5}{2}^-$ 7.75%	2162 2297 2548	$\frac{3}{2}^-$ ($\frac{5}{2}^-, \frac{1}{2}^-$) $\frac{3}{2}^-$	18 ± 5 { 104 = 10 or ^d 78 = 8 72 ± 8	38 ± 10 4.7 ± 0.5 or ^d 6.3 ± 0.7 9 ± 1	31 ± 8 ^c 11 ± 7 ^c
48, 0 ⁺ 73.45%	2421 3371 3700 3739	2 ₂ ⁺ 2 ₃ ⁺ 1 ^(*) 1 ⁺	0.74 = 0.18 5.5 = 0.6 20.4 = 2.3 101 = 10	44 = 12 16.1 ± 2.1 15.1 ± 1.6 4.2 ± 0.4	35 ± 7 ^e 18 ± 7 ^e 35 ± 3 ^g 16 ± 3 ^g
49, $\frac{1}{2}^-$ 5.51%	1623 1763	($\frac{3}{2}^-, \frac{5}{2}^-, \frac{1}{2}^-$) $\frac{3}{2}^-$	11.4 = 1.5 ^h 18.3 = 2.2	55 ± 7 36 ± 4.3	
50, 0 ⁺ 5.34%	1554 (4311)	2 ₁ ⁺ 2 ⁺	0.52 = 0.15 85 = 60	1300 ± 400 1 < τ < 6	$\Gamma = 0.48 \pm 0.04$ meV ⁱ < 80 ^j
(47, 49)	3917 2810		(90 ± 20) $\Gamma/g\Gamma_0$ ^k (29 = 4) $\Gamma/g\Gamma_0$ ^k		

^a Reference 11.

^b Assuming $\Gamma_0/\Gamma = 0.50$.

^c Reference 18.

^d The larger width and shorter lifetime correspond to spin $\frac{5}{2}$.

^e Reference 23.

^f Coulomb excitation and (e, e'), J. Heisenberg, J. S. McCarthy, and I. Sick, Nucl. Phys. A164, 353 (1971).

^g C. D. Kavaloski and W. J. Kossler, Phys. Rev. 180, 971 (1969).

^h Assuming spin $\frac{3}{2}$.

ⁱ From Coulomb excitation results of C. W. Towsley, D. Cline, and R. Horoshko, Nucl. Phys. A250, 381 (1975).

^j Reference 12.

^k Calculated as if ⁴⁸Ti, g is the statistical factor.

¹¹ P.A. Assimakopoulos, et al., Nucl. Phys. A180, 131 (1972).

¹² J. G. Pronko et al., Phys. Rev. C10, 1345 (1974).

¹⁸ J.J. Weaver et al., Nucl. Phys. A196, 269 (1972).

²³ T.T. Bardin et al., Phys. Rev. C7, 190 (1973).

T_I
 $A=48$

T_I
 $A=48$

T_I
 $A=48$

Method 320 MeV synchrotron; proton telescope; neutron counter

Ref. No.	JHH
60 St 1.	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$Ti^{48}(\gamma, np)$	Bremss. 320					$(\sigma/\sigma_{H^2}) = 5.6 \pm 0.8$ $[\sigma_{H^2} = 63 \mu b]$ Mean photon energy - 262 MeV Proton counter at 76°

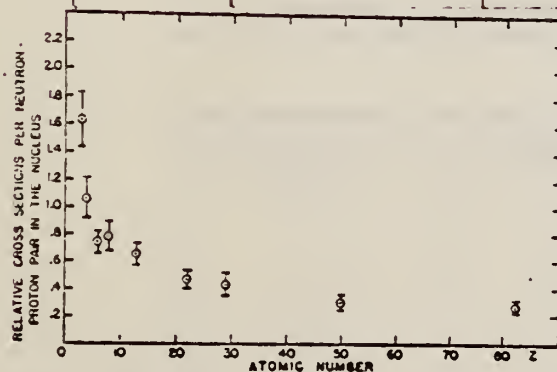


FIG. 2. Relative cross sections per neutron-proton pair in the nucleus versus atomic number. The cross section of the element of interest is divided by the cross section for deuterium and by the factor NZ/A .

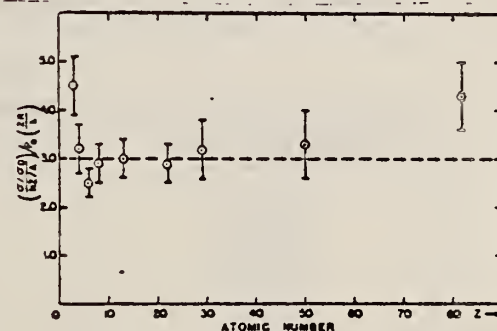


FIG. 3. The relative cross sections per neutron-proton pair corrected for the probability of escape is plotted against atomic number. The probability of escape factor is calculated using $r_0 = 1.30 \times 10^{-13}$ cm and $\lambda = 3.6 \times 10^{-13}$ cm. The probability of escape factor is given in expression (1). The data shown are those of Fig. 2 divided by $P(2R/\lambda)$.

Method Bremss.; Canberra electron synchrotron; activity

Ref. No.	EGF
62 Sh 5	

Reaction	E or ΔE
$^{48}\text{Ti}(\gamma, np)$	Bremss.
$^{48}\text{Ti}(\gamma, p)$	14-31

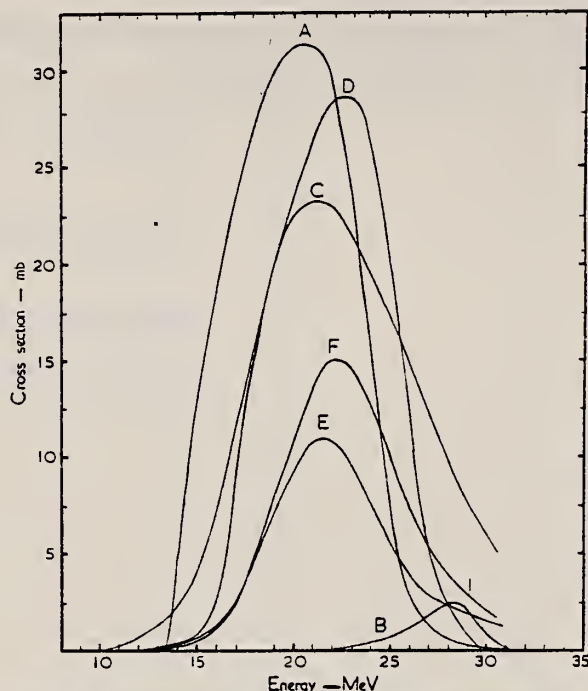


Fig. 2. Excitation function for the photo-disintegration of titanium. A: $^{46}\text{Ti}(\gamma, n) + 1.09$ $^{47}\text{Ti}(\gamma, 2n)$; B: $^{46}\text{Ti}(\gamma, np)$; C: $^{47}\text{Ti}(\gamma, p) + 10.1$ $^{48}\text{Ti}(\gamma, np)$; D: $^{48}\text{Ti}(\gamma, p) + 0.07$ $^{49}\text{Ti}(\gamma, np)$; E: $^{49}\text{Ti}(\gamma, p) + 0.96$ $^{50}\text{Ti}(\gamma, np)$; F: $^{50}\text{Ti}(\gamma, p)$.

TABLE 3
Integrated (to 31 MeV) cross sections

Reactions	Relative weights	Integrated cross section (MeV · mb)
$^{46}\text{Ti}(\gamma, n) : ^{47}\text{Ti}(\gamma, 2n)$	1 : 1.09	260 ± 34
$^{48}\text{Ti}(\gamma, np)$		$8.8 \pm 1.4^a)$
$^{47}\text{Ti}(\gamma, p) : ^{48}\text{Ti}(\gamma, np)$	1 : 10.1	246 ± 38
$^{49}\text{Ti}(\gamma, p) : ^{48}\text{Ti}(\gamma, np)$	1 : 0.07	217 ± 32
$^{49}\text{Ti}(\gamma, p) : ^{50}\text{Ti}(\gamma, np)$	1 : 0.96	86 ± 13
$^{50}\text{Ti}(\gamma, p)$		113 ± 32

^{a)} Upper limit. The partial cross section from the ^{44}Sc formed in the ground state is $4.4 \text{ MeV} \cdot \text{mb}$.

TABLE 4

Comparison of experimental results with statistical theory predictions for gamma rays of 22 MeV

Ratio of cross sections	Experimental	Theoretical
$\frac{^{47}\text{Ti}(\gamma, p)}{^{48}\text{Ti}(\gamma, p)}$	0.81	1.40
$\frac{^{49}\text{Ti}(\gamma, p)}{^{48}\text{Ti}(\gamma, p)}$	0.39	0.63
$\frac{^{50}\text{Ti}(\gamma, p)}{^{48}\text{Ti}(\gamma, p)}$	0.45	0.56
$\frac{^{49}\text{Ti}(\gamma, p)}{^{48}\text{Ti}(\gamma, p)}$	0.98	0.34

Notes
Table 3: $\text{Cu}^{63}(\gamma, n)$ by Berman and Brown [Phys. Rev. 96, 83 (1954)] used as standard.

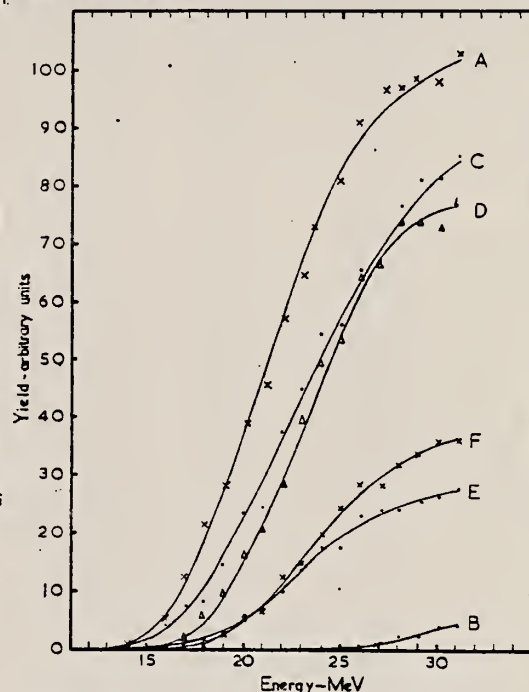


Fig. 1. Activation curves for the photo-disintegration of titanium. A: ^{46}Ti ; B: ^{44}Sc (ground state decay); C: ^{46}Sc ; D: ^{47}Sc ; E: ^{48}Sc ; F: ^{49}Sc .

REF. A. F. Akkerman, V.L. Kochetkov, V.N. Chekanov, V.V. Suvorov, A.K. Shtol'ts Zhur. Eksp. i Teoret. Fiz. <u>45</u> , 1778 (1963); Soviet Phys. JETP 18, 1218 (1964)				ELEM. SYM.	A	Z
				Ti	48	22

METHOD				REF. NO.		
Radioactive source; gaseous $V^{48}Cl_4$				63 Ak 1		NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	2	D	2	NAI-D		150
		(2.310)		(2.310)			

Lifetime of 2.310 MeV level (4^+) = $2^{+0.9}_{-0.7} \times 10^{-12}$ sec.

REF. E. C. Booth, B. Chasan and K. A. Wright
Nuc1. Phys. 57, 403-420 (1964)

ELEM. SYM.	A	Z
Ti	48	22
REF. NO.		
64 Bo 1		NVB

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G.G	LFT	1-3 (0.5 - 3.0)	C	1 - 3 (0.5 - 3.0)	NAI-D		100

ABI

TABLE I
Cases of observed resonance fluorescence

Nucleus multipol.	State (MeV)	Spin	Γ_0/Γ	$T(g_W \Gamma_0^2/\Gamma^2)^{-1}$ (sec).	Mean lifetime T BCW (sec)	Mean lifetime T other (sec)	Ref.	Γ_0/Γ_W BCW
Ti ⁴⁸	0.00	0 ⁺						
E2 ^a)	0.99	2 ⁺	1	$11 \pm 4 \times 10^{-13}$	$3.6 \pm 1.5 \times 10^{-13}$	$6 \times 10^{-13}, 14 \times 10^{-13}$ ^{a,17)}	18	
[E2] ^a)	2.30 ^b)	4 ⁺ [2 ⁺]	?	$6.7 \pm 2 \times 10^{-14}$	$21 \pm 9 (\Gamma_0/\Gamma)^2 \times 10^{-14}$			$5.6 \Gamma/\Gamma_0$

METHOD

REF. NO.

[Page 1 of 2]

67 Pa 2

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	RLY	THR- 30	C	22,30	ACT-I		4PI
G,NP	RLY	THR- 30	C	22,30	ACT-I		4PI

TABLE I

Yields, Y , and cross sections, σ , of the proton reactions in Ti isotopes excited by photons or neutrons. (The yields and cross sections with primes are "first proton" yields and cross sections)

Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 22 \text{ MeV}$				$E_n = 13 \text{ MeV}$		
		$Y_{\gamma p}$	$Y_{\gamma p\alpha}$	$Y_{\gamma np}$	$Y_{\gamma p}'$ (cols. 1 + 2)	σ_{np}	$\sigma_{n,p\alpha}$	σ_{np}' (cols. 5 + 6)
$^{47}\text{Ti}^*$	^{47}Ti ^{48}Ti	57	(<1) ^a	(<1)	~57	277	(<10)	~280
$^{48}\text{Ti}^*$	^{48}Ti ^{47}Ti	20	E.I. ^b	E.I.	20	121	34	155
$^{49}\text{Ti}^*$	^{49}Ti ^{48}Ti	9.2	<0.1	<0.1	9.2	69	<1	~70
$^{50}\text{Ti}^*$	^{50}Ti ^{49}Ti	9.6	E.I.	E.I.	9.6	29	<1	~30

Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 30 \text{ MeV}$				$E_n = 19 \text{ MeV}$		
		$Y_{\gamma p}$	$Y_{\gamma p\alpha}$	$Y_{\gamma np}$	$Y_{\gamma p}'$	σ_{np}	$\sigma_{n,p\alpha}$	σ_{np}'
$^{47}\text{Ti}^*$	^{47}Ti ^{48}Ti	5.5	(0.03)	(0.04)	5.5	167	47	214
$^{48}\text{Ti}^*$	^{48}Ti ^{47}Ti	2.5	0.24	0.41	2.7	77	70	147
$^{49}\text{Ti}^*$	^{49}Ti ^{48}Ti	1.5	0.29	0.57	1.8	42	31	73
$^{50}\text{Ti}^*$	^{50}Ti ^{49}Ti	1.6	0.17	0.37	1.8	28	9	37

^aBracketed values are calculated from yields for production of ^{48}Ti , as ^{48}Sc is stable.
^bE.I. = energetically impossible.

ELEM. SYM.	A	Z
Ti	48	22

METHOD	REF. NO.
	67 Pa 2

[Page 2 of 2]

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

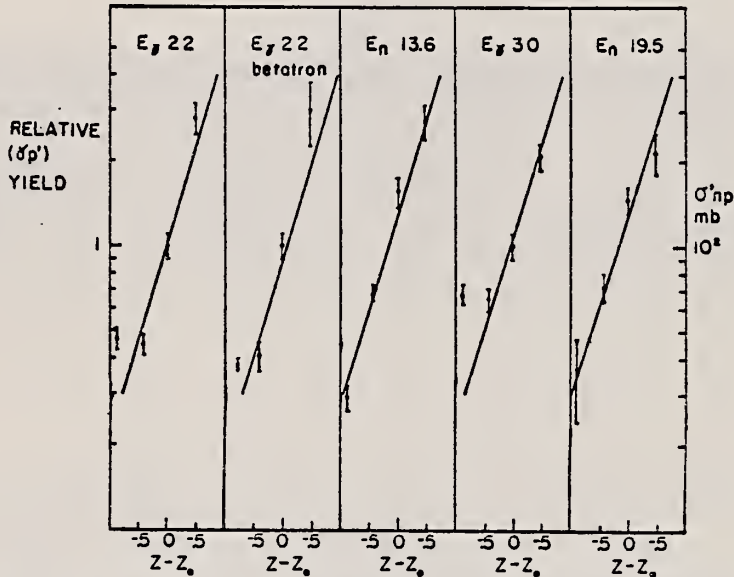


FIG. 1. The relative yields of the first-proton photoreactions in four Ti isotopes plotted as a function of $Z - Z_0$, where $Z = 22$ and Z_0 is the value of Z which minimizes $M(A, Z)$. For ^{46}Ti , $Z - Z_0 = -0.88$, and for ^{47}Ti , ^{48}Ti , and ^{49}Ti the values of $Z - Z_0$ are -0.44 , $+0.01$, and $+0.46$ respectively. Three plots are shown, one obtained at 22 MeV using the linac, one at 30 MeV with the linac, and one at 22 MeV with the betatron. Also shown are cross sections of the first-proton reactions induced by fast neutrons, of energies 13.6 and 19.5 MeV, in Ti isotopes (Pai 1966).

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	ABY	THR-20	C	20	ACT- I		4PI

TABLE I. SUMMARY OF DATA ON (γ, p) REACTIONS WITH 20 MeV BREMSSTRAHLUNG

Nuclide		S_p (MeV)	Observed γ -ray			Yield determined	
Parent (Natural abundance, %)	Residual (Half-life)		Energy (MeV)	Branching ratio (%)	Type of multipole transition	$\mu\text{Ci/mg}^a$	Yield/mol·R
^{23}Mg (10.11)	^{23}Na (15 hr)	12.06	1.37	100	E2	1.48×10^{-1}	1.7×10^3
^{28}Si (4.71)	^{28}Al (2.27 min)	12.33	1.78	100	E2	1.91	2.8×10^3
^{30}Si (3.12)	^{30}Al (6.56 min)	13.59	1.28	93.8	E2+M1	6.51×10^{-1}	1.5×10^3
^{40}Ca (2.06)	^{40}K (22.4 hr)	12.17	0.374	85	E2+M1	7.86×10^{-1}	1.3×10^3
^{47}Ti (7.32)	^{47}Sc (84.1 d)	10.47	0.887	100	E2	7.11×10^{-1}	3.1×10^3
^{48}Ti (73.99)	^{48}Sc (3.4 d)	11.44	0.160	100	E2+M1	6.83×10^{-1}	1.2×10^3
^{49}Ti (5.46)	^{49}Sc (1.8 d)	11.35	1.31	100	E2	4.40×10^{-1}	5.8×10^3
^{52}Cr (9.55)	^{52}V (3.8 min)	11.15	1.43	100	E2	5.01×10^{-1}	6.6×10^3
^{57}Fe (2.17)	^{57}Mn (2.58 hr)	10.57	1.81	23.5	E2+M1	8.10×10^{-2}	2.1×10^3
^{76}Ge (36.74)	^{76}Ga (4.8 hr)	10.92	0.295	97	(E2)	3.70×10^{-1}	1.3×10^3
^{77}Se (7.58)	^{77}As (26.5 hr)	9.61	0.559	41	E2	1.48×10^{-1}	1.3×10^3
^{87}Sr (7.02)	^{87}Rb (19 d)	9.41	1.08	9	E2	5.15×10^{-1}	9.9×10^3
^{114}Cd (12.26)	^{114}Ag (3.2 hr)	9.74	1.39	35	E2	1.91×10^{-2}	2.1×10^3
^{117}Sn (7.57)	^{117}In (54 min)	9.58	1.27	84	E2	9.80×10^{-3}	6.9×10^3
^{137}Ba (11.32)	^{137}Cs (13 d)	8.67	0.830	100	E2	1.68×10^{-1}	2.2×10^3
^{199}Hg (16.84)	^{199}Au (2.7 d)	7.27	0.412	100	E2	8.43×10^{-1}	2.2×10^3

a) The value corrected at the end of 1 hr irradiation (9.4×10^6 R/min).

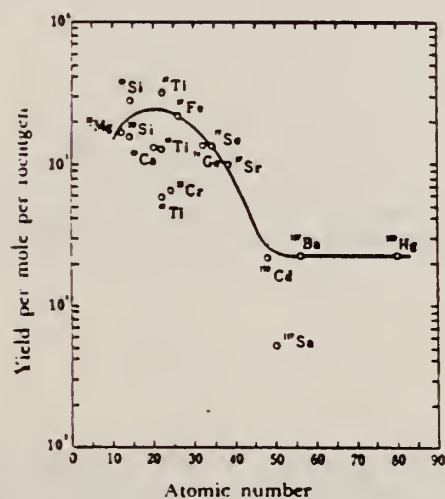


Fig. 2. The yield curve for the (γ, p) reaction with 20 MeV bremsstrahlung.

METHOD

REF. NO.

69 Ok 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G.P	RLY	THR-60	C	30-60	NAI-D		4PI

YLD REL 12C(G,N)TABLE 6. THE RELATIVE YIELDS FOR (γ , p) REACTIONS ON TITANIUM
NUCLEI EXPRESSED AS THOSE PER MOLE

Réaction	Yield per mole relative to $^{12}\text{C}(\gamma, n)^{11}\text{C}$			
	30 MeV	45 MeV	55 MeV	60 MeV
$^{47}\text{Ti}(\gamma, p)^{46}\text{Sc}$	5.4×10^{-1}	5.8×10^{-1}	5.4×10^{-1}	6.3×10^{-1}
$^{48}\text{Ti}(\gamma, p)^{47}\text{Sc}$	2.0×10^{-1}	2.4×10^{-1}	2.8×10^{-1}	2.8×10^{-1}
$^{49}\text{Ti}(\gamma, p)^{48}\text{Sc}$	1.2×10^{-1}	2.1×10^{-1}	2.2×10^{-1}	2.1×10^{-1}

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1-3	D	198-300	MAG-D		DST

3 LEVELS

TABLE 3
Inelastic parameters

Isotope	E^* (MeV)	L	Shape	c_{tr}^* (fm)	z_{tr}^* (fm)	G^* (s.p.u.)	R_w^* (fm)	G (s.p.u.) heavy-particle scattering ¹⁹⁾
⁴⁰ Ca	3.740	3	2	3.536 ± 0.030	1.483 ± 0.020	24.9 ± 1.0	4.835 ± 0.030	23.6 ± 3.5
	4.480	5	2	3.538 ± 0.050	1.260 ± 0.035	9.7 ± 0.6	4.810	17.7 ± 2.7
			3			17.7 ± 1.5	5.467 ± 0.060	11.3 ± 1.7
⁴² Ca	3.440	3	2	3.565 ± 0.018	1.383 ± 0.014	12.4 ± 0.5	4.719 ± 0.023	12.0 ± 1.8
	4.100	5	2	3.231 ± 0.030	1.404 ± 0.025	3.4 ± 0.3	4.816 ± 0.044	9.0 ± 1.4
⁴⁴ Ca	3.30	3	2	3.555 ± 0.018	1.313 ± 0.013	6.95 ± 0.28	4.618 ± 0.023	8.0 ± 1.2
	2.28	4	2	4.091 ± 0.030	1.268 ± 0.016	2.66 ± 0.15	5.135 ± 0.030	1.3 ± 0.3
	3.91	5	2	3.268 ± 0.030	1.397 ± 0.024	2.30 ± 0.20	4.832 ± 0.045	4.4 ± 0.7
⁴⁶ Ti	2.00	4	2	4.264 ± 0.021	1.229 ± 0.013	7.61 ± 0.30	5.226 ± 0.026	
⁴⁸ Ti	2.286	4	2	4.330 ± 0.021	1.196 ± 0.013	3.37 ± 0.15	5.237 ± 0.026	
⁵⁰ Ti	4.42	3	2	3.645 ± 0.017	1.244 ± 0.012	3.76 ± 0.15	4.600 ± 0.023	5.4 ± 0.8
								$5.9^{20)}$
	2.50	4	2	3.865 ± 0.017	1.347 ± 0.012	4.7 ± 0.15	5.064 ± 0.026	3.3 ± 0.7
	3.20	5	2	3.254 ± 0.032	1.345 ± 0.026	0.83 ± 0.08	4.724 ± 0.045	$2.7^{20)}$

Present experiment

^{a)} Errors do not reflect any model dependence.

^{b)} Given errors do not include the 6% error of normalization.

¹⁹⁾ A. M. Bernstein, Adv. in Nucl. Phys. 3 (1969) 325.

- 13) J. Simpson, J. Cookson, D. Eccleshall and M. Yates, Nucl. Phys. 62 (1965) 385
 14) G. M. Temmer and N. P. Heydenburg, Phys. Rev. 104 (1956) 967
 15) D. S. Andreyev, A. P. Grinberg, K. I. Erokhina and I. Kh. Lemberg, Nucl. Phys. 19 (1960) 400
 16) F. R. Metzger, Nucl. Phys. 27 (1961) 612
 17) W. H. Kelly and G. B. Beard, Nucl. Phys. 27 (1961) 188
 18) R. B. Begzhanov, A. A. Islamov, D. K. Kaipov and Yu. K. Shubnyi, JETP (Sov. Phys.) 17 (1963) 94

[over]

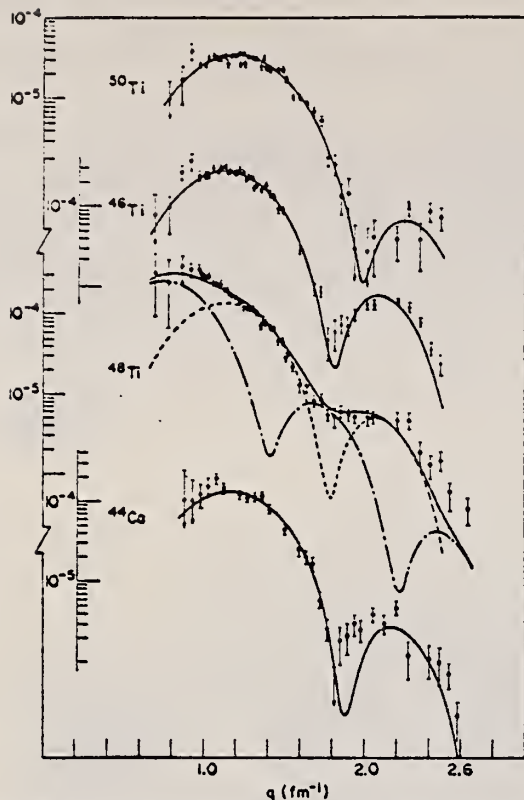


Fig. 6. Fits to ^{50}Ti , ^{46}Ti , ^{48}Ti and ^{44}Ca 2^+ levels. For ^{48}Ti we show the decomposition into contributions of the 2.42 MeV 2^+ level (dash-dot curve) and the 2.286 MeV 4^+ level (dashed curve).

TABLE 2
Inelastic parameters for 2^+ levels

Isotope	E^* (MeV)	$B(E2)$ Coulomb Excit. ($e^2 \cdot \text{fm}^4$)	Shape	c_{1r}^a (fm)	z_{1r}^a (fm)	Fitted $B(E2)$ ($e^2 \cdot \text{fm}^4$) ^{b)}	R_{1r}^a (fm)	$B(E2)(e^2 \cdot \text{fm}^4)$ heavy-particle scattering			
^{42}Ca	1.520	364 ± 82 ⁹⁾	2	3.541 ± 0.025	1.459 ± 0.020	320 ± 20	4.619 ± 0.030	476 ± 74 ¹⁹⁾			
^{44}Ca	1.160	350 ± 70 ¹⁰⁾	2	3.691 ± 0.027	1.428 ± 0.020	480 ± 30	4.704 ± 0.030	507 ± 100 ¹⁹⁾			
			1	3.454 ± 0.025	0.690 ± 0.010	1270 ± 85	5.553 ± 0.030	.			
^{46}Ti	3.259	830 ± 170 ¹⁴⁾	2			54 ± 10					
			2	3.807 ± 0.014	1.397 ± 0.010	740 ± 20	4.763 ± 0.017	867 ²⁰⁾			
^{48}Ti	0.984	560 ± 100 ¹³⁾	1	3.562 ± 0.014	0.669 ± 0.005	1680 ± 50	5.510 ± 0.020	738 ¹¹⁾			
			2	3.777 ± 0.014	1.340 ± 0.010	537 ± 15	4.671 ± 0.017	788 ± 120 ¹⁹⁾			
			1	3.539 ± 0.014	0.633 ± 0.005	1110 ± 30	5.321 ± 0.020	673 ¹¹⁾			
^{50}Ti	2.420	700 ± 140 ¹⁴⁾	2					659 ²⁰⁾			
			2			49 ± 8		57 ± 10 ¹⁹⁾			
			1	3.768 ± 0.014	1.255 ± 0.010	307 ± 10	4.567 ± 0.017	349 ²⁰⁾			
^{56}Fe	1.580	240 ± 20 ¹²⁾	2	3.535 ± 0.014	0.576 ± 0.005	515 ± 17	5.047 ± 0.020	260 ²¹⁾			
			2					431 ²⁴⁾			
			2	4.320	877 ± 70 ⁹⁾	2	4.048 ± 0.024	1.357 ± 0.014	945 ± 45	4.919 ± 0.025	72 ²⁴⁾
			1	0.880	877 ± 70 ⁹⁾	1	3.878 ± 0.024	0.651 ± 0.006	1570 ± 70	5.454 ± 0.030	
Present experiment											

^{a)} Errors do not reflect any model dependence.

^{b)} Given errors do not include the 6% error of normalization.

^{c)} Average for $B(E2)$ formed from values of refs. ¹²⁻¹⁸⁾.

ELEM. SYM.	A	Z
Ti	48	22
REF. NO.	72 Li 1	
	egf	

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	0-3	D	60-120	MAG-D		DST

.99, 2.44 MEV

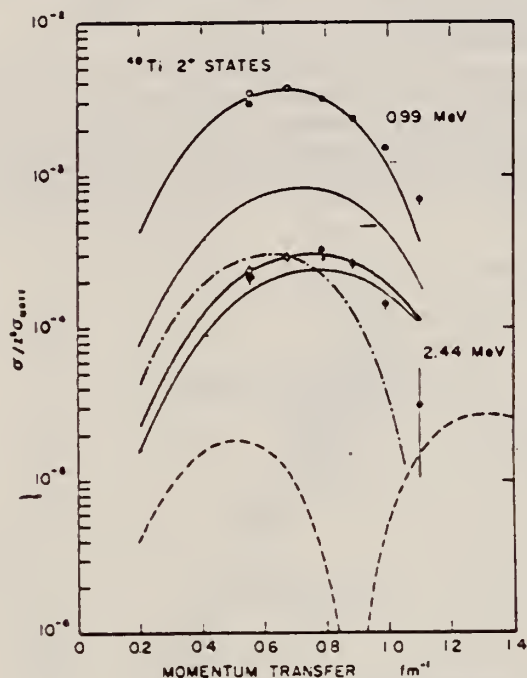


Fig. 2. Electron scattering form factors for the lowest two 2^+ states in ^{49}Ti . Solid lines were calculated using a best fit admixture and phase. The dashed line represents the harmonic two-phonon form factor. The dot-dashed line represents a best fit attempt for the 2_2^+ state with $\phi = 0$. The shaded area was determined using an admixture which fit the measured BR for $\phi = \pi$. For clarity the $\phi = 0$ BR fit region is not shown.

METHOD	REF. NO.	
	76 Ra 1	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, G	LFT	2- 4	C	1- 5	SCD-D		DST
		(3.371-3.739)		(1.3-4.7)			

4 LEV, 2421-3739 KEV

TABLE II. Mean lives of some levels in the titanium isotopes.

Mass no., ground state, spin, & abund.	Level energy (keV)	Level spin	Γ_0 (meV)	τ (pres. meas.) (fs)	τ (other) (fs)
46, 0 ⁺ 7.95%	3168 4316	1 ⁻ 1	7.3 ± 2.0 (172 ± 26) Γ/Γ_0	41 ± 12 0.96 ± 0.14 ^b	71 ± 12 ^a <44 ^a
47, $\frac{1}{2}^-$ 7.75%	2162 2297 2548	$\frac{3}{2}^-$ ($\frac{5}{2}^-, \frac{7}{2}^-$) $\frac{1}{2}^-$	18 ± 5 { 104 ± 10 or ^d 78 ± 8 72 ± 8	38 ± 10 4.7 ± 0.5 or ^d 6.3 ± 0.7 9 ± 1	31 ± 8 ^c 11 ± 7 ^c
48, 0 ⁺ 73.45%	2421 3371 3700 3739	2 ₂ ⁺ 2 ₃ ⁺ 1 ⁽⁺⁾ 1 ⁺	0.74 ± 0.18 5.5 ± 0.6 20.4 ± 2.3 101 ± 10	44 ± 12 16.1 ± 2.1 15.1 ± 1.6 4.2 ± 0.4	35 ± 7 ^e { $\Gamma_0 = 0.66 \pm 0.11$ meV and 0.77 ± 0.14 ^f 18 ± 7 ^e 35 ± 3 ^g 16 ± 3 ^g
49, $\frac{1}{2}^-$ 5.51%	1623 1763	($\frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$) $\frac{1}{2}^-$	11.4 ± 1.5 ^h 18.3 ± 2.2	55 ± 7 36 ± 4.3	
50, 0 ⁺ 5.34% (47, 49)	1554 (4311) 3917 2810	2 ₁ ⁺ 2 ⁺	0.52 ± 0.15 85 ± 60 (90 ± 20) $\Gamma/g\Gamma_0$ ^k (29 ± 4) $\Gamma/g\Gamma_0$ ^k	1300 ± 400 1 < τ < 6	$\Gamma = 0.48 \pm 0.04$ meV ⁱ <80 ^j

^a Reference 11.

^b Assuming $\Gamma_0/\Gamma = 0.50$.

^c Reference 18.

^d The larger width and shorter lifetime correspond to spin $\frac{1}{2}$.

^e Reference 23.

^f Coulomb excitation and (e, e'), J. Heisenberg, J. S. McCarthy, and I. Sick, Nucl. Phys. A164, 353 (1971).

^g C. D. Kavaloski and W. J. Kossler, Phys. Rev. 180, 971 (1969).

^h Assuming spin $\frac{1}{2}$.

ⁱ From Coulomb excitation results of C. W. Towsley, D. Cline, and R. Horoshko, Nucl. Phys. A250, 381 (1975).

^j Reference 12.

^k Calculated as if ⁴⁹Ti, g is the statistical factor.

¹¹ P.A. Assimakopoulos, et al., Nucl. Phys. A180, 131 (1972).

¹² J.G. Pronko et al., Phys. Rev. C10, 1345 (1974).

¹⁸ J.J. Weaver et al., Nucl. Phys. A196, 269 (1972).

²³ T.T. Bardin et al., Phys. Rev. C7, 190 (1973).

METHOD

REF. NO.

78 Ma 10

hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	ABY	11-68	C	30-68	ACT		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

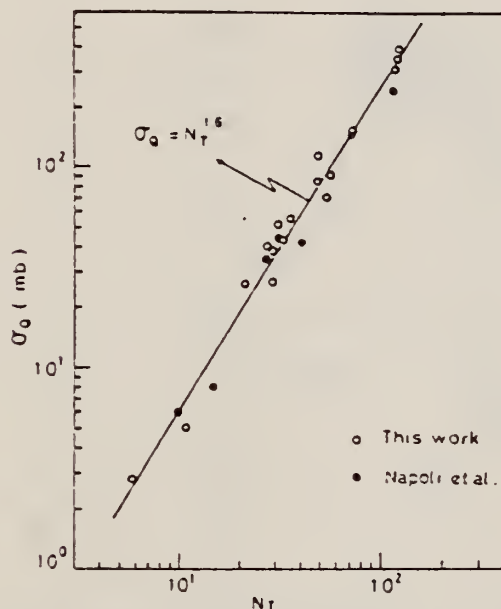


Fig. 2. Yield per equivalent quanta versus target neutron number.

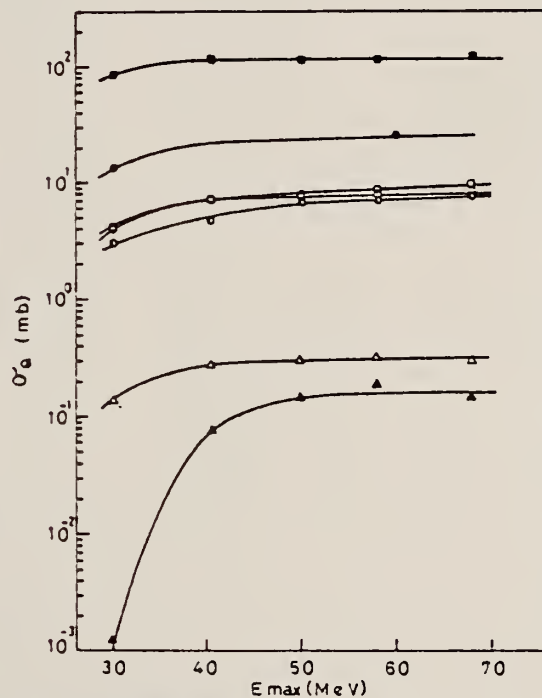


Fig. 4. Activation yield curves for the reactions on Ca, Ti and V.

■ $^{48}\text{Ca}(\gamma, n)^{47}\text{Ca}$, □ $^{44}\text{Ca}(\gamma, p)^{43}\text{K}$, ● $^{46}\text{Ti}(\gamma, n)^{45}\text{Ti}$,
 ○ $^{48}\text{Ti}(\gamma, p)^{47}\text{Sc}$, ● $^{49}\text{Ti}(\gamma, p)^{48}\text{Sc}$, △ $^{51}\text{V}(\gamma, \alpha)^{47}\text{Sc}$,
 ▲ $^{51}\text{V}(\gamma, zn)^{46}\text{Sc}$.

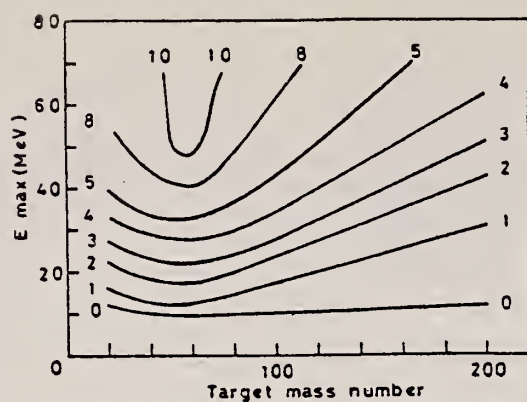


Fig. 10. Yields of the (γ, p) reactions as a function of bremsstrahlung maximum energy and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

METHOD					REF. NO.		hg
					80 Su 6		
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	11-28	C	11-28	BF3-I		4PI

Abstract: A high resolution measurement of the $^{48}\text{Ti}(\gamma, n)$ cross section is reported. Evidence for isospin splitting of the giant dipole resonance is found to be consistent with the prediction. In addition the deformation splitting of the GDR is consistent with predictions of the dynamic collective model.

E NUCLEAR REACTIONS $^{48}\text{Ti}(\gamma, n)$, $E \approx 15\text{--}27.5$ MeV; measured $\sigma(E, \theta)$; ^{48}Ti deduced GDR splitting. Dynamic collective model.

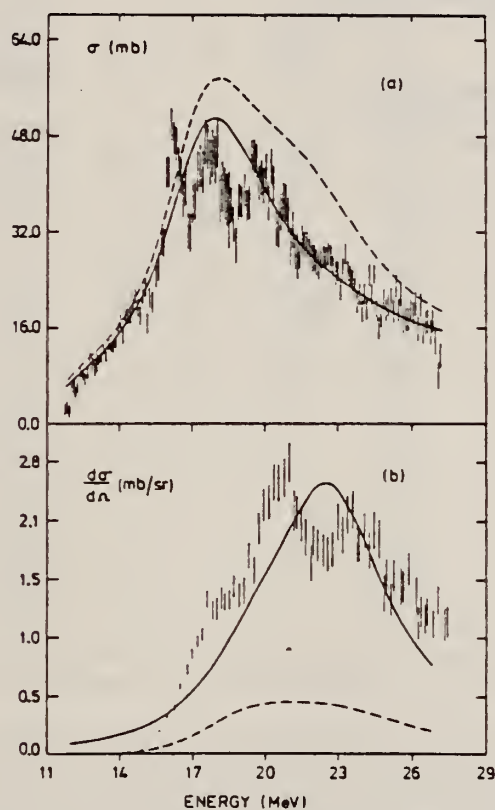


Fig. 1. (a) The ^{48}Ti photoneutron cross section. Vertical bars show statistical errors only. (b) The ^{48}Ti photoproton differential cross section, measured at $\theta = 90^\circ$, from ref. ¹⁰). Curves show a statistical model calculation of the shape of the photonuclear cross sections of ^{48}Ti . Solid lines show the calculation if isospin effects are included, compared to the $^{48}\text{Ti}(\gamma, n)$ (a) and $^{48}\text{Ti}(\gamma, p)$ (b) cross sections. The broken line results if the calculation ignores isospin.

METHOD

REF. NO.

81 Ca 2

hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	1 (.984)	C	0 - 2	SCD-D		

.984 MeV

Abstract. Lifetimes of 49 excited states below 1.65 MeV have been measured in ^{24}Mg , ^{27}Al , ^{48}Ti , ^{58}Ni , ^{59}Co , $^{61,62}\text{Ni}$, $^{63,65}\text{Cu}$, $^{64,66,68}\text{Zn}$, ^{75}As , ^{103}Rh , $^{113,115}\text{In}$, $^{116,118,120}\text{Sn}$ and $^{121,123}\text{Sb}$ by means of nuclear resonance fluorescence experiments. The levels are excited by bremsstrahlung x-ray photons. The self-absorption technique applied to suitable cases provides nuclear absorption cross sections, widths and lifetimes from which the x-ray spectral distributions are also obtained. Scattering experiments are performed for all other cases in order to obtain widths and lifetimes from these x-ray photon curves. The Compton effect in the sample is taken into account. Self-absorption provides $g\Gamma_0$ from which Γ is deduced using adopted J^π and Γ_0/Γ values; scattering provides $u = g(\Gamma_0^2/\Gamma)W(\theta)$ from which Γ is also deduced with J , Γ_0/Γ and mixing ratios taken from the literature. Thanks to simultaneous determination of the x-ray spectra all the lifetimes as given by our programs with their statistical errors form an unusually coherent set of values.

NUCLEAR REACTIONS (γ , γ), bremsstrahlung excitation; natural isotopes: ^{24}Mg , ^{27}Al , ^{48}Ti , ^{58}Ni , ^{59}Co , $^{61,62}\text{Ni}$, $^{63,65}\text{Cu}$, $^{64,66,68}\text{Zn}$, ^{75}As , ^{103}Rh , $^{113,115}\text{In}$, $^{116,118,120}\text{Sn}$ and $^{121,123}\text{Sb}$; $E \approx 0.5-1.65$ MeV; measured $g\Gamma_0$ or $g(\Gamma_0^2/\Gamma)W(\theta)$; deduced $T_{1/2}$.

(OVER)

Tableau 3. Résultats des mesures des niveaux étudiés par diffusion.

Table 3. Results obtained using the diffusion method.

Isotope	Energie (keV)	J^π	J_0^π	Γ_0/Γ	δ	$u = g(\Gamma_0^2/\Gamma)W(\theta)$ (meV)	τ (ps) ce travail	τ_{ref} (ps)	Références †
²⁴ Mg	1368,59(4)	2 ⁺	0 ⁺	1	E2	1,08(13)	1,76(21)	1,98(4)	Endt et van der Leun (1978)
²⁷ Al	1014,45(3)	1 ⁺	1 ⁺	0,971	+ 0,351(12)	0,186(13)	2,20(16)	2,12(8)	Endt et van der Leun (1978)
⁴⁴ Ti	983,512(3)	2 ⁺	0 ⁺	1	E2	0,282(23)	6,74(55)	6,1(13)	Been (1978)
⁵⁸ Ni	1454,45(15)	2 ⁺	0 ⁺	1	E2	2,11(26)	0,90(11)	0,92(3)	Kocher et Auble (1976)
⁵⁹ Co	1099,224(25)	1 ⁺	1 ⁺	1	(E2)	0,069(8)	4,79(55)	3,17(58)	Kim (1976)
⁵⁹ Co	1458,8(3)	1 ⁺	1 ⁺	0,91	(E2)	0,68(8)	1,17(14)	1,52(16)	Kim (1976)
⁵⁹ Co	1480,9(3)	1 ⁺	1 ⁺	0,8	< 0,35 ^a	1,23(15)	0,254(31)	0,31(3)	Kim (1976)
⁶¹ Ni	1185,7(6)	1 ⁺	1 ⁺	0,77(8) ⁱ	[0,14]	1,88(49)	0,21(5)	0,16(3)	Andreev <i>et al</i> (1974)
⁶² Ni	1172,91(9)	2 ⁺	0 ⁺	1	E2	0,88(17)	2,15(42)	2,09(3)	Halbert (1979a)
⁶³ Cu	1327,00(7)	1 ⁺	1 ⁺	0,84	(E2)	1,04(14)	0,84(11)	0,88(4)	Auble (1979b)
⁶³ Cu	1412,05(4)	1 ⁺	1 ⁺	0,72	+ 0,61{ ⁻⁹ / ₈ }	0,260(38)	1,90(28)	1,61(3)	Auble (1979b)
⁶⁴ Zn	991,54(7)	2 ⁺	0 ⁺	1	E2	0,640(54)	2,97(25)	2,60(13)	Halbert (1979b)
⁶⁵ Cu	1481,83(5)	1 ⁺	1 ⁺	0,85	(E2)	1,13(19)	0,79(13)	0,49(5)	Auble (1975a)
⁶⁶ Zn	1039,37(6)	2 ⁺	0 ⁺	1	E2	0,70(6)	2,71(23)	2,25(15)	Auble (1975b)
⁶⁶ Zn	1077,38(5)	2 ⁺	0 ⁺	1	E2	0,70(6)	2,71(23)	2,34(23)	Lewis (1975)
⁷³ As	572,5(10)	1 ⁺	1 ⁺	1 ^d	0,39 ^b	0,236(26)	4,14(46)	3,5(9)	Horen et Lewis (1975)
⁷³ As	823,0(10)	1 ⁺	1 ⁺	0,86 ^d	(E2)	0,214(22)	4,27(43)	3,5(3)	Robinson <i>et al</i> (1967)
⁷³ As	865,5(10)	1 ⁺	1 ⁺	0,83 ^d	— ^c	0,78(6)	0,863(68)	0,60(12)	Celliers <i>et al</i> (1977)
⁷³ As	1076,0(10)	1 ⁺	1 ⁺	0,94 ^d	0,38 ^d	1,97(13)	0,287(19)	0,32(7)	Celliers <i>et al</i> (1977)
⁷³ As	1128,5(10)	1 ⁺	1 ⁺	1	E1 ^d	0,224(24)	1,47(16)	—	—
⁷³ As	1349,0(10)	1 ⁺	1 ⁺	0,67 ^d	0,20 ^d	1,61(29)	0,180(32)	0,12(3)	Wilson (1970)
⁷³ As	1370,0(10)	1 ⁺	1 ⁺	0,47 ^d	0,47 ^d	0,64(13)	0,218(44)	—	—
¹⁰³ Rh	803,1(2)	1 ⁺	1 ⁺	0,70	M1	1,85(16)	0,174(15)	—	Harmatz (1979)
¹⁰³ Rh	1277,0(2)	1 ⁺	1 ⁺	0,75	- 0,62(30) ^e	0,81(9)	0,87(10)	1,3(9)	Harmatz (1979)
¹¹³ In	1177(1)	1 ⁺	1 ⁺	1	+ 0,5(2)	9,1(8)	0,086(8)	0,10(6)	Tuttle <i>et al</i> (1976)
¹¹³ In	1510(1)	1 ⁺	1 ⁺	0,935	- 0,5{ ⁻² / ₃ }	6,4(9)	0,071(10)	0,11{ ⁻² / ₃ }	Tuttle <i>et al</i> (1976)
¹¹³ In	1077,7(10)	1 ⁺	1 ⁺	0,81 ^j	(E2)	0,159(24)	1,61(24)	1,23(7)	Tuttle <i>et al</i> (1976)
¹¹³ In	1290,59(3)	1 ⁺	1 ⁺	0,98 ^j	(E2)	1,31(11)	0,66(6)	0,55(4)	Tuttle <i>et al</i> (1976)
¹¹³ In	1448,78(3)	1 ⁺	1 ⁺	0,86	- 8 ^f	0,90(11)	0,50(6)	0,52(20)	Tuttle <i>et al</i> (1976)
¹¹³ In	1486,1(1)	1 ⁺	1 ⁺	0,787	- 0,8 ^f	0,63(9)	0,63(9)	0,4(3)	Tuttle <i>et al</i> (1976)
¹¹⁵ In	1497,2(4)	(1 ⁺)	(1 ⁺)	< 1	(E2)	1,33(16)	< 0,30(4)	—	—
¹¹⁵ In	1607,8(15)	(1 ⁺)	(1 ⁺)	≤ 1	(E2)	1,54(24)	≤ 0,26(4)	—	—
¹¹⁶ Sn	1293,54(2)	2 ⁺	0 ⁺	1	E2	3,58(37)	0,53(6)	0,522(14)	Carlson <i>et al</i> (1975)
¹¹⁶ Sn	1229,64(4)	2 ⁺	0 ⁺	1	E2	2,75(28)	0,69(7)	0,67(2)	Carlson <i>et al</i> (1976)
¹²⁰ Sn	1171,6(2)	2 ⁺	0 ⁺	1	E2	1,83(16)	1,04(9)	0,91(2)	Kocher (1976)
¹²¹ Sb	1023,5(10)	1 ⁺	1 ⁺	1	[0,57] ^k	3,69(34)	0,228(21)	0,20(7) ^h	Tamura <i>et al</i> (1979)
¹²¹ Sb	1105,5(10)	1 ⁺	1 ⁺	0,4	—	0,47(4)	0,42(4)	—	—
¹²¹ Sb	1142,5(10)	1 ⁺	1 ⁺	0,6	(E2)	0,85(8)	0,449(40)	0,41(8) ^h	Booth <i>et al</i> (1973)
¹²¹ Sb	1384,0(10)	1 ⁺	1 ⁺	1	[0,45] ^k	4,7(5)	0,092(10)	0,088(14) ^h	Booth <i>et al</i> (1973)
¹²³ Sb	1029,5(10)	1 ⁺	1 ⁺	1	[0,57] ^k	2,96(27)	0,272(25)	0,26(4) ^h	Booth <i>et al</i> (1973)
¹²³ Sb	1086,5(10)	1 ⁺	1 ⁺	1	[δ] > 1,26 ^k	1,06(9)	0,67(6)	0,72(15) ^h	Booth <i>et al</i> (1973)

† Références pour les colonnes 3, 4, 5, 6 et 9 de chaque ligne, sauf indication appelée au bas de ce tableau. Pour les autres données se reporter au texte.

Remarque. Pour calculer δ^2 quand nous ne disposons que de $B(E2)$, pour un mélange $(E2) + (M1)$, nous déduisons $g\Gamma_0(E2) \propto B(E2)E^2$; en admettant $W(\theta) = 1$ et connaissant Γ_0/Γ , notre détermination de u donne une première approximation de $g\Gamma_0$ d'où une valeur de $\delta^2 = (g\Gamma_0(E2))/(g\Gamma_0 - g\Gamma_0(E2))$ qui permet d'améliorer $W(\theta)$ et $g\Gamma_0$ de proche en proche.

^a Swann (1971); ^b Robinson *et al* (1967); ^c $W(\theta) = 0,99$ calculé d'après la formule de Celliers *et al* (1977); ^d Abbondanno *et al* (1978); ^e Sayer *et al* (1972); ^f Tuttle *et al* (1976); ^g d'après $B(E2)$ de Barnes *et al* (1966); ^h calculé d'après Booth *et al* (1973); ⁱ Williams *et al* (1975); ^j Dietrich *et al* (1970).

\overline{T}_I
A=49

\overline{T}_I
A=49

\overline{T}_I
A=49

Method Bremss.; Canberra electron synchrotron; activity

Ref. No.	EGF
62 Sh 5	

Reaction	E or ΔE
$\text{Ti}^{49}(\gamma, np)$	Bremss.
$\text{Ti}^{49}(\gamma, p)$	14-31

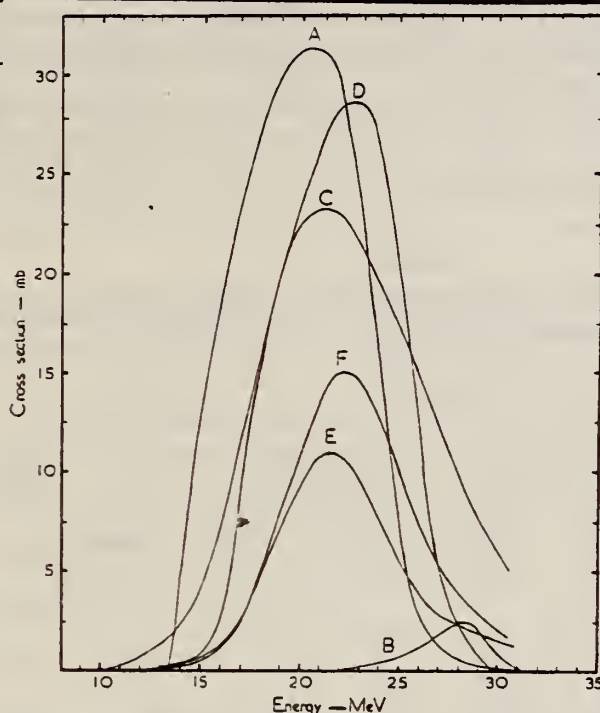


Fig. 2. Excitation function for the photo-disintegration of titanium. A: $^{46}\text{Ti}(\gamma, n) + 1.09$ $^{47}\text{Ti}(\gamma, 2n)$; B: $^{46}\text{Ti}(\gamma, np)$; C: $^{47}\text{Ti}(\gamma, p) + 10.1$ $^{48}\text{Ti}(\gamma, np)$; D: $^{46}\text{Ti}(\gamma, p) + 0.07$ $^{46}\text{Ti}(\gamma, np)$; E: $^{46}\text{Ti}(\gamma, p) + 0.96$ $^{46}\text{Ti}(\gamma, np)$; F: $^{50}\text{Ti}(\gamma, p)$.

TABLE 3
Integrated (to 31 MeV) cross sections

Reactions	Relative weights	Integrated cross section (MeV · mb)
$^{46}\text{Ti}(\gamma, n) : ^{47}\text{Ti}(\gamma, 2n)$	1 : 1.09	260 ± 34
$^{46}\text{Ti}(\gamma, np)$		8.8 ± 1.4 ^{a)}
$^{47}\text{Ti}(\gamma, p) : ^{48}\text{Ti}(\gamma, np)$	1 : 10.1	246 ± 38
$^{46}\text{Ti}(\gamma, p) : ^{46}\text{Ti}(\gamma, np)$	1 : 0.07	217 ± 32
$^{46}\text{Ti}(\gamma, p) : ^{50}\text{Ti}(\gamma, np)$	1 : 0.96	86 ± 13
$^{50}\text{Ti}(\gamma, p)$		113 ± 32

^{a)} Upper limit. The partial cross section from the ^{44}Sc formed in the ground state is 4.4 MeV · mb.

TABLE 4

Comparison of experimental results with statistical theory predictions for gamma rays of 22 MeV

Ratio of cross sections	Experimental	Theoretical
$\frac{^{47}\text{Ti}(\gamma, p)}{^{50}\text{Ti}(\gamma, p)}$	0.81	1.40
$\frac{^{46}\text{Ti}(\gamma, p)}{^{50}\text{Ti}(\gamma, p)}$	0.39	0.63
$\frac{^{50}\text{Ti}(\gamma, p)}{^{46}\text{Ti}(\gamma, p)}$	0.45	0.56
$\frac{^{46}\text{Ti}(\gamma, p)}{^{46}\text{Ti}(\gamma, n)}$	0.98	0.34

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(8-1-63)
USCOMM-OC 18356-P63

Notes

Table 3: $\text{Cu}^{63}(\gamma, n)$ by Berman and Brown [Phys. Rev. 96, 83 (1954)] used as standard.

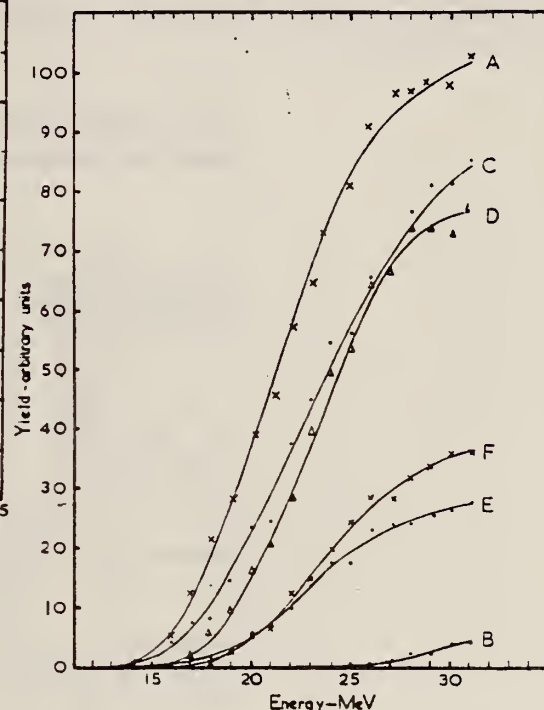


Fig. 1. Activation curves for the photo-disintegration of titanium. A: ^{46}Ti ; B: ^{44}Sc (ground state decay); C: ^{46}Sc ; D: ^{47}Sc ; E: ^{48}Sc ; F: ^{49}Sc .

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	RLY	THR- 30	C	22,30	ACT-I		4PI
G,NP	RLY	THR- 30	C	22,30	ACT-I		4PI

TABLE I
Yields, Y , and cross sections, σ , of the proton reactions in Ti isotopes excited by photons or neutrons. (The yields and cross sections with primes are "first proton" yields and cross sections)

Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 22 \text{ MeV}$				$E_n = 13 \text{ MeV}$		
		$Y_{\gamma p}$	$Y_{\gamma pn}$	$Y_{\gamma np}$	$Y_{\gamma p}'$ (cols. 1 + 2)	σ_{np}	$\sigma_{n,pn}$	σ_{np}' (cols. 5 + 6)
$^{47}\text{Ti}^*$	^{47}Ti ^{46}Ti	57	(<1) ^a	(<1)	~57	277	(<10)	~280
$^{48}\text{Ti}^*$	^{48}Ti ^{47}Ti	20	E.I. ^b	E.I.	20	121	34	155
$^{49}\text{Ti}^*$	^{49}Ti ^{48}Ti	9.2	<0.1	<0.1	9.2	69	<1	~70
$^{50}\text{Ti}^*$	^{50}Ti ^{49}Ti	9.6	E.I.	E.I.	9.6	29	<1	~30

Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 30 \text{ MeV}$				$E_n = 19 \text{ MeV}$		
		$Y_{\gamma p}$	$Y_{\gamma pn}$	$Y_{\gamma np}$	$Y_{\gamma p}'$	σ_{np}	$\sigma_{n,pn}$	σ_{np}'
$^{47}\text{Ti}^*$	^{47}Ti ^{46}Ti	5.5	(0.03)	(0.04)	5.5	167	47	214
$^{48}\text{Ti}^*$	^{48}Ti ^{47}Ti	2.5	0.24	0.41	2.7	77	70	147
$^{49}\text{Ti}^*$	^{49}Ti ^{48}Ti	1.5	0.29	0.57	1.8	42	31	73
$^{50}\text{Ti}^*$	^{50}Ti ^{49}Ti	1.6	0.17	0.37	1.8	28	9	37

^a Bracketted values are calculated from yields for production of ^{46}Ti , as ^{46}Sc is stable.
^b E.I. = energetically impossible.

REF. H. L. Pai and K. G. McNeill Can. J. Phys. <u>45</u> , 3235 (1967)				ELEM. SYM.	A	Z
				Ti	49	22
METHOD				REF. NO.		
				[Page 2 of 2] 67 Pa 2		EGF
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE

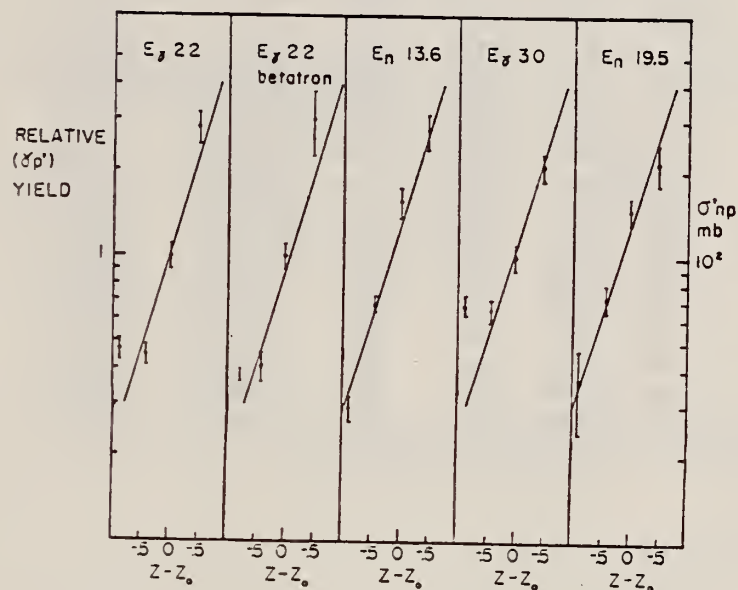


FIG. 1. The relative yields of the first-proton photoreactions in four Ti isotopes plotted as a function of $Z - Z_0$, where $Z = 22$ and Z_0 is the value of Z which minimizes $M(A, Z)$. For ^{46}Ti , $Z - Z_0 = -0.88$, and for ^{48}Ti , ^{49}Ti , and ^{50}Ti the values of $Z - Z_0$ are -0.44 , $+0.01$, and $+0.46$ respectively. Three plots are shown, one obtained at 22 MeV using the linac, one at 30 MeV with the linac, and one at 22 MeV with the betatron. Also shown are cross sections of the first-proton reactions induced by fast neutrons, of energies 13.6 and 19.5 MeV, in Ti isotopes (Pai 1968).

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, P	ABY	THR-20	C	20	ACT-I		4PI

TABLE I. SUMMARY OF DATA ON (γ, p) REACTIONS WITH 20 MeV BREMISTRAHLUNG

Nuclide		S _p (MeV)	Observed γ-ray			Yield determined	
Parent (Natural abundance, %)	Residual (Half-life)		Energy (MeV)	Branching ratio (%)	Type of multipole transition	μCi/mg ^{a)}	Yield/mol·R
²³ Mg (10.11)	²⁴ Na (15 hr)	12.06	1.37	100	E2	1.48×10 ⁻¹	1.7×10 ⁵
²⁸ Si (4.71)	²⁹ Al (2.27 min)	12.33	1.78	100	E2	1.91	2.8×10 ⁵
³⁰ Si (3.12)	²⁹ Al (6.56 min)	13.59	1.28	93.8	E2+M1	6.51×10 ⁻¹	1.5×10 ⁵
⁴⁴ Ca (2.06)	⁴² K (22.4 hr)	12.17	0.374	85	E2+M1	7.86×10 ⁻³	1.3×10 ⁵
⁴⁷ Ti (7.32)	⁴⁶ Sc (84.1 d)	10.47	0.887	100	E2	7.11×10 ⁻⁴	3.1×10 ⁵
⁴⁸ Ti (73.99)	⁴⁷ Sc (3.4 d)	11.44	0.160	100	E2+M1	6.83×10 ⁻³	1.2×10 ⁵
⁴⁸ Ti (5.46)	⁴⁸ Sc (1.8 d)	11.35	1.31	100	E2	4.40×10 ⁻³	5.8×10 ⁴
⁵² Cr (9.55)	⁵² V (3.8 min)	11.15	1.43	100	E2	5.01×10 ⁻¹	6.6×10 ⁴
⁵⁷ Fe (2.17)	⁵⁶ Mn (2.58 hr)	10.57	1.81	23.5	E2+M1	8.10×10 ⁻³	2.1×10 ⁵
⁷⁴ Ge (36.74)	⁷³ Ga (4.8 hr)	10.92	0.295	97	(E2)	3.70×10 ⁻¹	1.3×10 ⁵
⁷⁷ Se (7.58)	⁷⁶ As (26.5 hr)	9.61	0.559	41	E2	1.48×10 ⁻²	1.3×10 ⁵
⁸⁷ Sr (7.02)	⁸⁶ Rb (19 d)	9.41	1.08	9	E2	5.15×10 ⁻⁴	9.9×10 ⁴
¹¹⁰ Cd (12.26)	¹¹² Ag (3.2 hr)	9.74	1.39	35	E2	1.91×10 ⁻²	2.1×10 ⁴
¹¹⁷ Sn (7.57)	¹¹⁸ mIn (54 min)	9.58	1.27	84	E2	9.80×10 ⁻³	6.9×10 ⁵
¹⁸⁷ Ba (11.32)	¹⁸⁶ Cs (13 d)	8.67	0.830	100	E2	1.68×10 ⁻⁴	2.2×10 ⁴
¹⁹⁹ Hg (16.84)	¹⁹⁸ Au (2.7 d)	7.27	0.412	100	E2	8.43×10 ⁻⁴	2.2×10 ⁴

a) The value corrected at the end of 1 hr irradiation (9.4×10⁴ R/min).

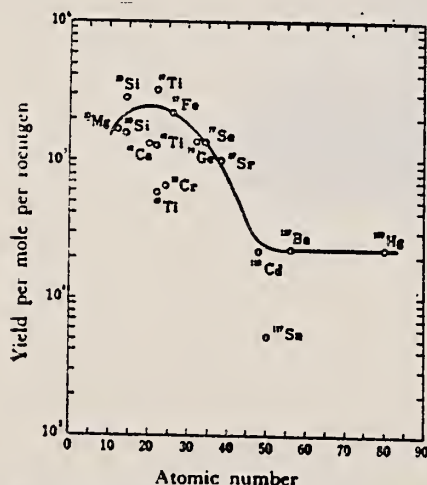


Fig. 2. The yield curve for the (γ, p) reaction with 20 MeV bremsstrahlung.

METHOD					REF. NO.		
					69 0x 1		hmg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G.P	RLY	THR-60	C	30-60	NAI-D		4PI

YLD REL 12C(γ ,N)

TABLE 6. THE RELATIVE YIELDS FOR (γ , p) REACTIONS ON TITANIUM
NUCLEI EXPRESSED AS THOSE PER MOLE

Reaction	Yield per mole relative to $^{12}\text{C}(\gamma, n)^{11}\text{C}$			
	30 MeV	45 MeV	55 MeV	60 MeV
$^{47}\text{Ti}(\gamma, p)^{46}\text{Sc}$	5.4×10^{-1}	5.8×10^{-1}	5.4×10^{-1}	6.3×10^{-1}
$^{48}\text{Ti}(\gamma, p)^{47}\text{Sc}$	2.0×10^{-1}	2.4×10^{-1}	2.8×10^{-1}	2.8×10^{-1}
$^{49}\text{Ti}(\gamma, p)^{48}\text{Sc}$	1.2×10^{-1}	2.1×10^{-1}	2.2×10^{-1}	2.1×10^{-1}

ELEM. SYM.	A	Z
Ti	49	22
REF. NO.		
76 Ra 1		hmg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, G	LFT	1, 1	C	1- 5	SCD-D		DST
		(1.623, 1.763)		(1.3-4.7)			

1623, 1763 KEV

TABLE II. Mean lives of some levels in the titanium isotopes.

Mass no., ground state, spin, & abund.	Level energy (keV)	Level spin	Γ_0 (meV)	τ (pres. meas.) (fs)	τ (other) (fs)
46, 0 ⁺ 7.95%	3168 4316	1 ⁻ 1	7.3 ± 2.0 (172 ± 26) Γ/Γ_0	41 ± 12 0.96 ± 0.14 ^b	71 ± 12 ^a <44 ^a
47, $\frac{5}{2}^-$ 7.75%	2162 2297 2548	$\frac{3}{2}^-$ ($\frac{5}{2}^-, \frac{7}{2}^-$) $\frac{3}{2}^-$	18 ± 5 { 104 ± 10 or ^d 78 ± 8 72 ± 8	38 ± 10 4.7 ± 0.5 or ^d 6.3 ± 0.7 9 ± 1	21 ± 8 ^c 11 ± 7 ^c
48, 0 ⁺ 73.45%	2421 3371 3700 3739	2 $\frac{1}{2}^+$ 2 $\frac{3}{2}^+$ 1 ^(*) 1 ⁺	0.74 ± 0.18 5.5 ± 0.6 20.4 ± 2.3 101 ± 10	44 ± 12 16.1 ± 2.1 15.1 ± 1.6 4.2 ± 0.4	35 ± 7 ^e { $\Gamma_0 = 0.66 \pm 0.11$ meV and 0.77 ± 0.14 ^f 13 ± 7 ^e 35 ± 3 ^g 16 ± 3 ^g
49, $\frac{1}{2}^-$ 5.51%	1623 1763	($\frac{3}{2}^-, \frac{5}{2}^-, \frac{7}{2}^-$) $\frac{5}{2}^-$	11.4 ± 1.5 ^h 18.3 ± 2.2	55 ± 7 36 ± 4.3	
50, 0 ⁺ 5.34% (47, 49)	1554 (4311) 3917 2810	2 $\frac{1}{2}^+$ 2 ⁺ 2 ⁺	0.52 ± 0.15 85 ± 60 (90 ± 20) $\Gamma/g\Gamma_0$ ^k (29 ± 4) $\Gamma/g\Gamma_0$ ^k	1300 ± 400 1 < τ < 6	$\Gamma = 0.48 \pm 0.04$ meV ⁱ <80 ^j

^a Reference 11.^b Assuming $\Gamma_0/\Gamma = 0.50$.^c Reference 18.^d The larger width and shorter lifetime correspond to spin $\frac{5}{2}$.^e Reference 23.^f Coulomb excitation and (e, e'), J. Heisenberg, J. S. McCarthy, and I. Sick, Nucl. Phys. A164, 353 (1971).^g C. D. Kavaloski and W. J. Kossler, Phys. Rev. 180, 971 (1969).^h Assuming spin $\frac{3}{2}$.ⁱ From Coulomb excitation results of C. W. Towsley, D. Cline, and R. Horoshko, Nucl. Phys. A250, 381 (1975).^j Reference 12.^k Calculated as if ⁴⁹Ti, g is the statistical factor.¹¹ P.A. Assimakopoulos, et al., Nucl. Phys. A180, 131 (1972).¹² J.G. Pronko et al., Phys. Rev. C10, 1345 (1974).¹⁸ J.J. Weaver et al., Nucl. Phys. A196, 269 (1972).²³ T.T. Bardin et al., Phys. Rev. C7, 190 (1973).

ELEM. SYM.	A	Z
Ti	49	22
REF. NO.		hg
78 Ma 10		

METHOD			REF. NO.		hg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,P	ABY	11-68	C	30-68	4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

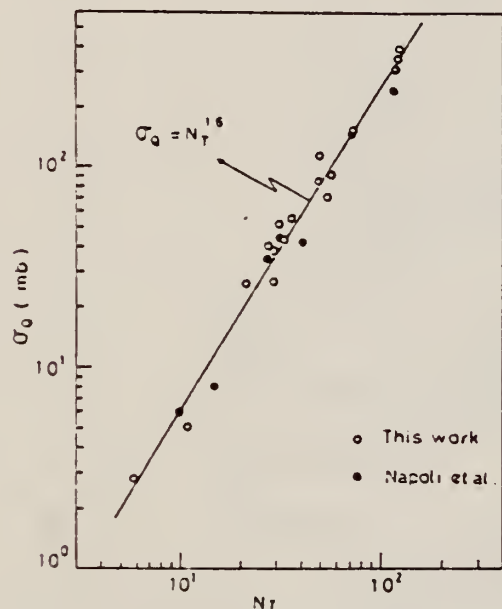


Fig. 2. Yield per equivalent quanta versus target neutron number.

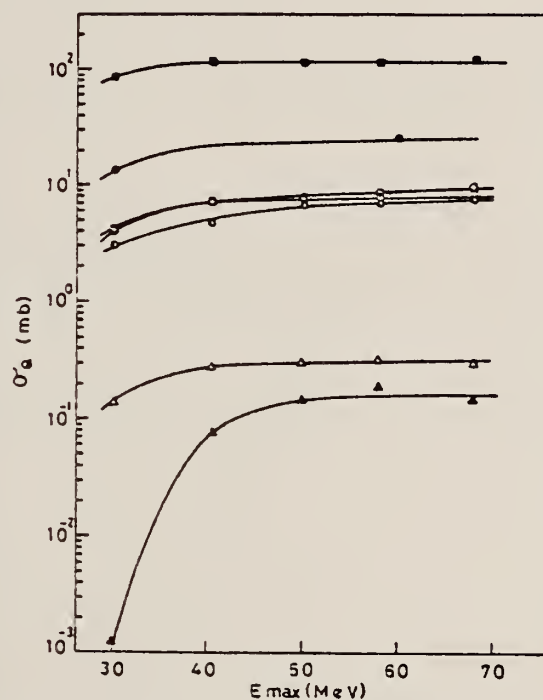


Fig. 4. Activation yield curves for the reactions on Ca, Ti and V.

■ $^{48}\text{Ca}(\gamma, n)^{47}\text{Ca}$, □ $^{44}\text{Ca}(\gamma, p)^{43}\text{K}$, ● $^{46}\text{Ti}(\gamma, n)^{45}\text{Ti}$,
○ $^{48}\text{Ti}(\gamma, p)^{47}\text{Sc}$, ○ $^{49}\text{Ti}(\gamma, p)^{48}\text{Sc}$, △ $^{51}\text{V}(\gamma, z)^{47}\text{Sc}$,
▲ $^{51}\text{V}(\gamma, xn)^{46}\text{Sc}$.

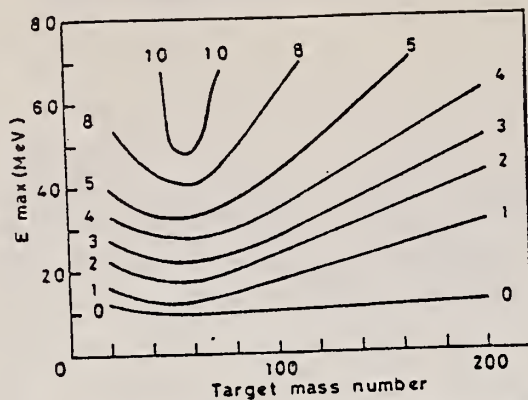


Fig. 10. Yields of the (γ, p) reactions as a function of bremsstrahlung maximum energy and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

ELEM. SYM.	A	Z
Ti	49	22
REF. NO.		hg
81 Be 10		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	NOX	9 (8.884)	D	9 (8.884)	SCD-D		DST
G,N	SPC	9 (8.884)	D	9 (8.884)	MOD-D		DST

Abstract: An unbound level in ^{49}Ti at 8884 keV was photoexcited using a γ -beam obtained from the $\text{Cr}(n, \gamma)$ reaction. The γ -decay and n-decay properties of this level were studied using angular distributions and polarization measurements. Thus spin and parity assignments of some levels in ^{49}Ti were made. The neutron width and the total radiative widths of the 8884 keV level were determined to be: $\Gamma_n = 0.25 \pm 0.05$ eV, $\Gamma_\gamma = 2.55 \pm 0.80$ eV.

G,G 8.884 MEV, J-PI=7/2+
G,N DECAY, 8.884MEV, LEV

E NUCLEAR REACTIONS $^{49}\text{Ti}(\gamma, \gamma')$: measured E_γ , $I_\gamma(\theta)$. ^{49}Ti deduced levels, J , π , E , Γ_γ , Γ_n .

Z. Berant et al. ^{49}Ti

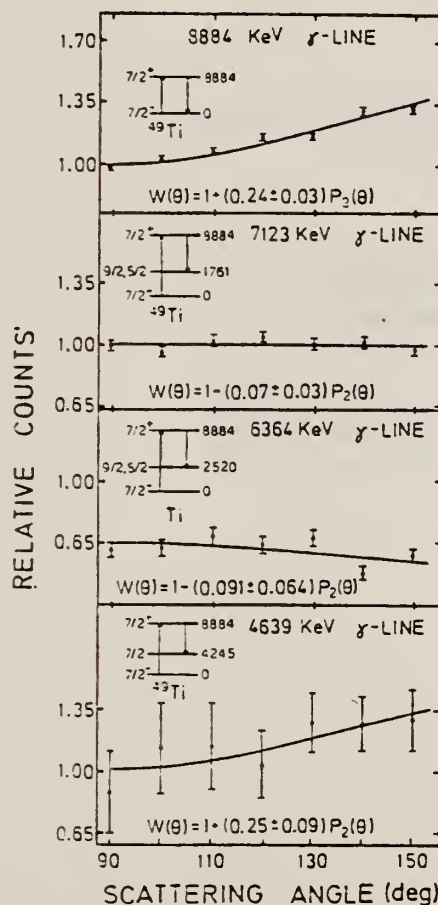


Fig. 2. Angular distribution of the elastic and inelastically scattered γ -lines from ^{49}Ti . The solid lines are least-square fits to the experimental distributions and have the form $W(\theta) = 1 + AP_2(\cos \theta)$.

(OVER)

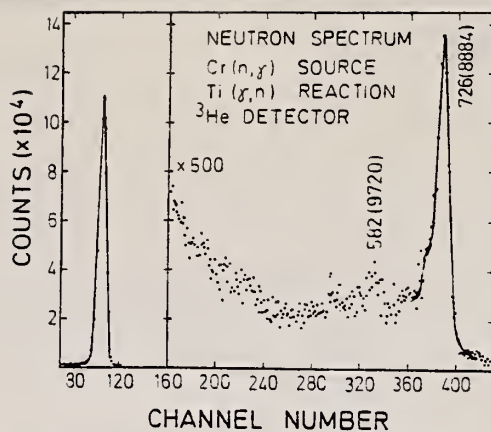


Fig. 3. Photoneutron spectrum of the $^{49}\text{Ti}(\gamma, n)$ reaction showing the strong n-group at 726 keV arising from the n-emission from the 8884 keV resonance level to the ^{48}Ti ground state. The weak n-group at 582 keV is produced by the 9720 keV γ -line proceeding to the 983 keV level in ^{48}Ti .

Z. Berant et al. / ^{49}Ti

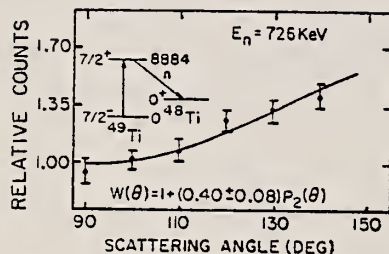


Fig. 4. Angular distribution of the 826 keV n-group as measured using a ^3He n-spectrometer. The generation process of this n-group through the $^{49}\text{Ti}(\gamma, n)$ reaction is shown.

TABLE 2

Measured values of Γ_0 , Γ_γ , the elastic scattering cross sections σ_e , the neutron emission cross section σ_n , the energy separation δ (between the incident γ -line and resonance level), the deduced value of the radiative widths Γ_0 , Γ_γ and the neutron width Γ_n for the ^{49}Ti level at 8884 keV

E_r (keV)	Γ_0, Γ_γ	σ_n (mb)	σ_e (mb)	δ (eV)	Γ_0 (eV)	Γ_n (eV)	Γ_γ (eV)
8884	0.13 ± 0.05	33 ± 4	43 ± 4	9.0 ± 0.8	0.33 ± 0.040	0.25 ± 0.05	2.54 ± 0.80

T_I
 $A=50$

T_I
 $A=50$

T_I
 $A=50$

METHOD				REF. NO.		
Betatron				58 Si 4		NVB
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,P	RLX	12 - 22	C	THR-22	ACT-I	4PI

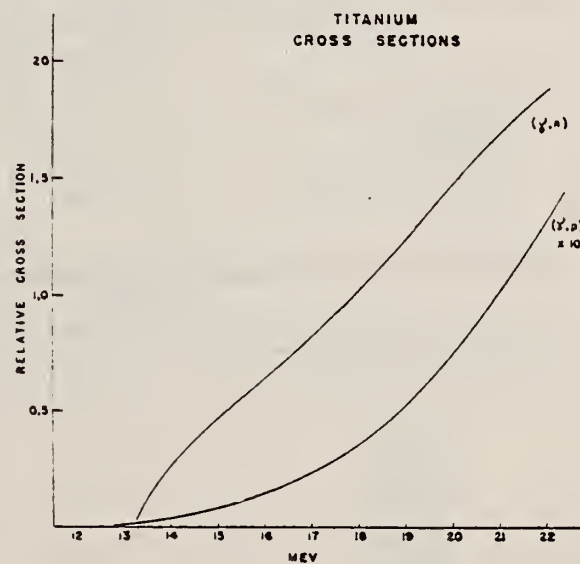


Fig. 4

Elem. Sym.	A	Z
Ti	50	22
Ref. No.	EGF	
62 Sh 5		

Method Bremss.; Canberra electron synchrotron; activity

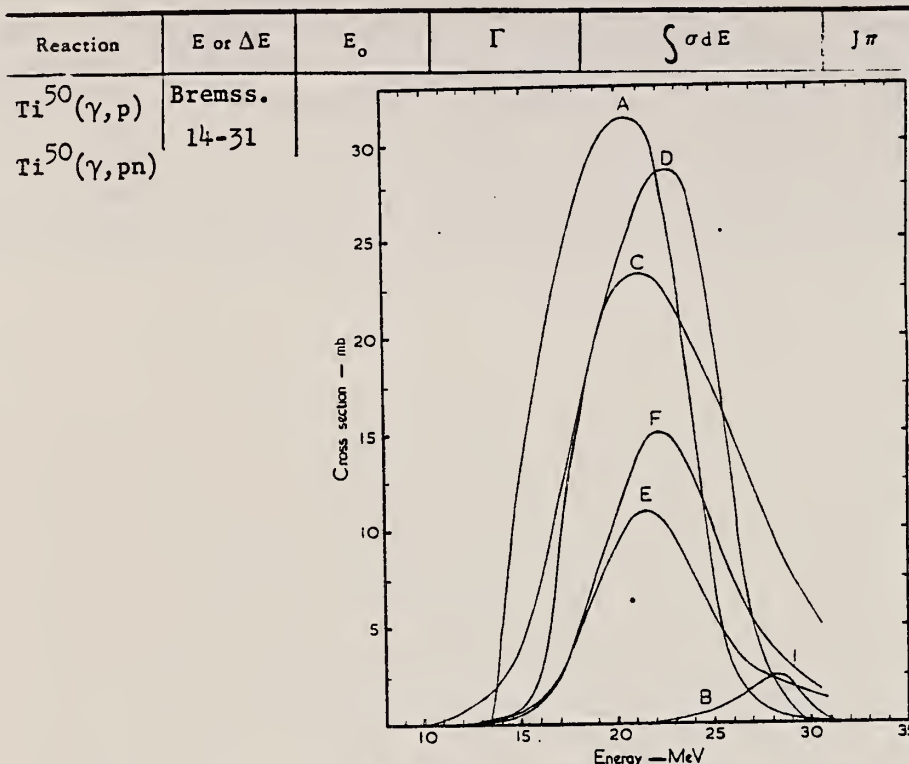


Fig. 2. Excitation function for the photo-disintegration of titanium. A: $^{46}\text{Ti}(\gamma, n) + 1.09 \text{ }^{47}\text{Ti}(\gamma, 2n)$; B: $^{46}\text{Ti}(\gamma, np)$; C: $^{47}\text{Ti}(\gamma, p) + 10.1 \text{ }^{48}\text{Ti}(\gamma, np)$; D: $^{48}\text{Ti}(\gamma, p) + 0.07 \text{ }^{49}\text{Ti}(\gamma, np)$; E: $^{49}\text{Ti}(\gamma, p) + 0.96 \text{ }^{50}\text{Ti}(\gamma, np)$; F: $^{50}\text{Ti}(\gamma, p)$.

TABLE 3
Integrated (to 31 MeV) cross sections

Reactions	Relative weights	Integrated cross section (MeV · mb)
$^{46}\text{Ti}(\gamma, n) : ^{47}\text{Ti}(\gamma, 2n)$	1 : 1.09	280 ± 34
$^{46}\text{Ti}(\gamma, np)$		$8.8 \pm 1.4^a)$
$^{47}\text{Ti}(\gamma, p) : ^{48}\text{Ti}(\gamma, np)$	1 : 10.1	246 ± 38
$^{48}\text{Ti}(\gamma, p) : ^{49}\text{Ti}(\gamma, np)$	1 : 0.07	217 ± 32
$^{49}\text{Ti}(\gamma, p) : ^{50}\text{Ti}(\gamma, np)$	1 : 0.96	86 ± 13
$^{50}\text{Ti}(\gamma, p)$		113 ± 32

a) Upper limit. The partial cross section from the ^{44}Sc formed in the ground state is $4.4 \text{ MeV} \cdot \text{mb}$.

TABLE 4

Comparison of experimental results with statistical theory predictions for gamma rays of 22 MeV

Ratio of cross sections	Experimental	Theoretical
$\frac{^{47}\text{Ti}(\gamma, p)}{^{48}\text{Ti}(\gamma, p)}$	0.81	1.40
$\frac{^{48}\text{Ti}(\gamma, p)}{^{49}\text{Ti}(\gamma, p)}$	0.39	0.63
$\frac{^{49}\text{Ti}(\gamma, p)}{^{50}\text{Ti}(\gamma, p)}$	0.45	0.56
$\frac{^{48}\text{Ti}(\gamma, p)}{^{46}\text{Ti}(\gamma, p)}$	0.98	0.34
$\frac{^{46}\text{Ti}(\gamma, n)}{^{46}\text{Ti}(\gamma, p)}$		

Table 3: $\text{Cu}^{63}(\gamma, n)$ by Berman and Brown [Phys. Rev. 96, 83 (1954)] used as standard.

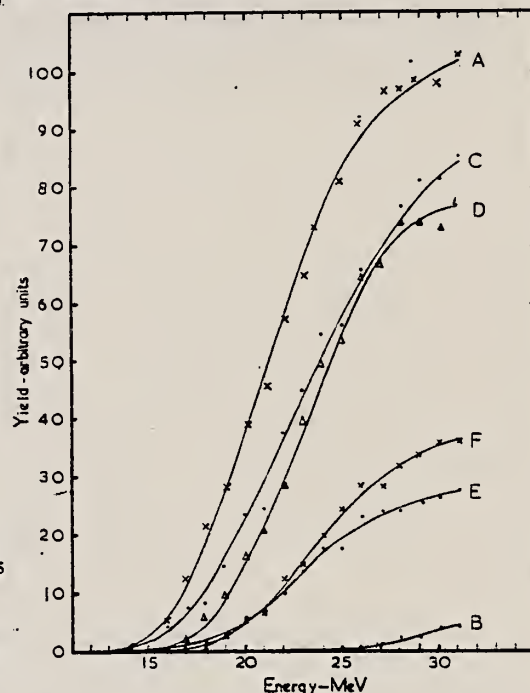


Fig. 1. Activation curves for the photo-disintegration of titanium. A: ^{46}Ti ; B: ^{44}Sc (ground state decay); C: ^{44}Sc ; D: ^{46}Sc ; E: ^{48}Sc ; F: ^{49}Sc .

METHOD

REF. NO.

[Page 1 of 2]

67 Pa 2

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	RLY	THR- 30	C	22,30	ACT-I		4PI
G,NP	RLY	THR- 30	C	22,30	ACT-I		4PI

TABLE I

Yields, Y , and cross sections, σ , of the proton reactions in Ti isotopes excited by photons or neutrons. (The yields and cross sections with primes are "first proton" yields and cross sections)

Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 22 \text{ MeV}$				$E_n = 13 \text{ MeV}$		
		$Y_{\gamma p}$	$Y_{\gamma pa}$	$Y_{\gamma np}$	$Y'_{\gamma p}$ (cols. 1 + 2)	σ_{np}	σ_{npa}	σ'_{np} (cols. 5 + 6)
$^{47}\text{Ti}^*$	^{47}Ti	57	(<1) ^a	(<1)	~57	277	(<10)	~280
$^{48}\text{Ti}^*$	^{48}Ti	20	E.I. ^b	E.I.	20	121	34	155
$^{49}\text{Ti}^*$	^{49}Ti	9.2	<0.1	<0.1	9.2	69	<1	~70
$^{50}\text{Ti}^*$	^{50}Ti	9.6	E.I.	E.I.	9.6	29	<1	~30
Compound nucleus	Target nucleus	1	2	3	4	5	6	7
		$E_\gamma = 30 \text{ MeV}$				$E_n = 19 \text{ MeV}$		
		$Y_{\gamma p}$	$Y_{\gamma pa}$	$Y_{\gamma np}$	$Y'_{\gamma p}$	σ_{np}	σ_{npa}	σ'_{np}
$^{47}\text{Ti}^*$	^{47}Ti	5.5	(0.03)	(0.04)	5.5	167	47	214
$^{48}\text{Ti}^*$	^{48}Ti	2.5	0.24	0.41	2.7	77	70	147
$^{49}\text{Ti}^*$	^{49}Ti	1.5	0.29	0.57	1.8	42	31	73
$^{50}\text{Ti}^*$	^{50}Ti	1.6	0.17	0.37	1.8	28	9	37

^aBracketed values are calculated from yields for production of ^{44}Ti , as ^{44}Sc is stable.
^bE.I. = energetically impossible.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

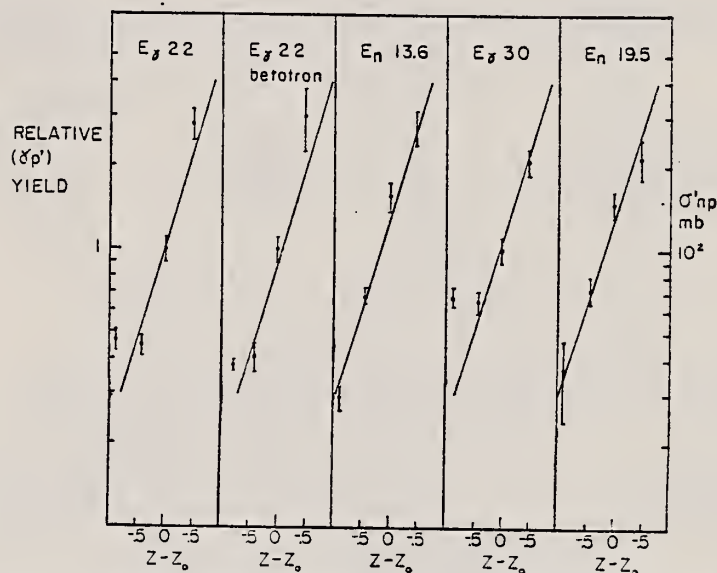


FIG. 1. The relative yields of the first-proton photoreactions in four Ti isotopes plotted as a function of $Z - Z_0$, where $Z = 22$ and Z_0 is the value of Z which minimizes $M(A, Z)$. For ^{46}Ti , $Z - Z_0 = -0.88$, and for ^{48}Ti , ^{49}Ti , and ^{47}Ti the values of $Z - Z_0$ are -0.44 , $+0.01$, and $+0.46$ respectively. Three plots are shown, one obtained at 22 MeV using the linac, one at 30 MeV with the linac, and one at 22 MeV with the betatron. Also shown are cross sections of the first-proton reactions induced by fast neutrons, of energies 13.6 and 19.5 MeV, in Ti isotopes (Pai 1966).

REF. J. Heisenberg, J. S. McCarthy and I. Sick
Nucl. Phys. A164, 353 (1971)

ELEM. SYM.	A	Z
Ti	50	22

METHOD

REF. NO.

71 He 1

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,E/	FME	1-5	D	198-300	MAG-D		DST

5 LEVELS

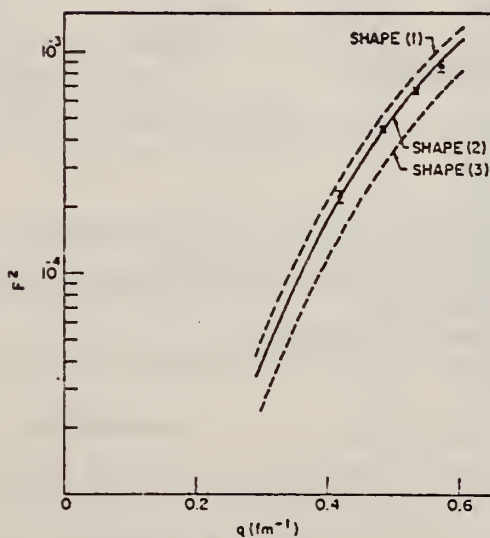


Fig. 5. Low-energy data for ^{40}Ca 3^- level from ref. ⁸). The curves represent the best fits to our high-energy data using shapes (1), (2) and (3) as explained in the text.

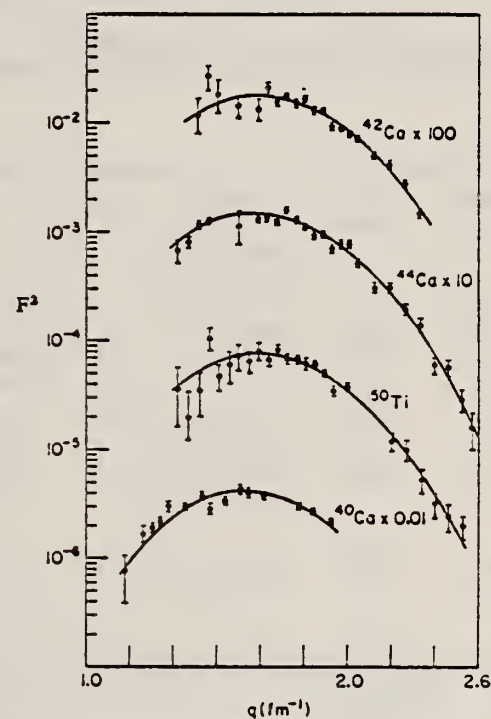


Fig. 7. Fits to ^{42}Ca , ^{40}Ca , ^{44}Ca and ^{50}Ti 5^- levels.

[over]

TABLE 3

Inelastic parameters

Isotope	E^* (MeV)	L	Shape	$c_{ir}^a)$ (fm)	$z_{ir}^a)$ (fm)	$G^b)$ (s.p.u.)	$R_{ir}^a)$ (fm)	$G(\text{s.p.u.})$ heavy-particle scattering ¹⁹⁾
⁴⁰ Ca	3.740	3	2	3.536 ± 0.030	1.483 ± 0.020	24.9 ± 1.0	4.835 ± 0.030	23.6 ± 3.5
	4.480	5	2	3.538 ± 0.050	1.260 ± 0.035	9.7 ± 0.6	4.810	17.7 ± 2.7
			3			17.7 ± 1.5	5.467 ± 0.060	11.3 ± 1.7
⁴² Ca	3.440	3	2	3.565 ± 0.018	1.383 ± 0.014	12.4 ± 0.5	4.719 ± 0.023	12.0 ± 1.8
	4.100	5	2	3.231 ± 0.030	1.404 ± 0.025	3.4 ± 0.3	4.816 ± 0.044	9.0 ± 1.4
⁴⁴ Ca	3.30	3	2	3.555 ± 0.018	1.313 ± 0.013	6.95 ± 0.28	4.618 ± 0.023	8.0 ± 1.2
	2.28	4	2	4.091 ± 0.030	1.268 ± 0.016	2.66 ± 0.15	5.135 ± 0.030	1.3 ± 0.3
	3.91	5	2	3.268 ± 0.030	1.397 ± 0.024	2.30 ± 0.20	4.832 ± 0.045	4.4 ± 0.7
	2.00	4	2	4.264 ± 0.021	1.229 ± 0.013	7.61 ± 0.30	5.226 ± 0.026	
⁴⁶ Ti	2.286	4	2	4.330 ± 0.021	1.196 ± 0.013	3.37 ± 0.15	5.237 ± 0.026	
⁵⁰ Ti	4.42	3	2	3.645 ± 0.017	1.244 ± 0.012	3.76 ± 0.15	4.600 ± 0.023	5.4 ± 0.8 $5.9^{20)}$
	2.50	4	2	3.865 ± 0.017	1.347 ± 0.012	4.7 ± 0.15	5.064 ± 0.026	3.3 ± 0.7 $2.7^{20)}$
	3.20	5	2	3.254 ± 0.032	1.345 ± 0.026	0.83 ± 0.08	4.724 ± 0.045	

Present experiment

*) Errors do not reflect any model dependence.

b) Given errors do not include the 6% error of normalization.

19) A. M. Bernstein, Adv. in Nucl. Phys. 3 (1969) 325.

TABLE 2

Inelastic parameters for 2⁺ levels

Isotope	E^* (MeV)	$B(E2)$ Coulomb Excit. ($e^2 \cdot \text{fm}^4$)	Shape	$c_{ir}^a)$ (fm)	$z_{ir}^a)$ (fm)	Fitted $B(E2)$ ($e^2 \cdot \text{fm}^4$) ^{b)}	$R_{ir}^a)$ (fm)	$B(E2)(e^2 \cdot \text{fm}^4)$ heavy-particle scattering
⁴² Ca	1.520	$364 \pm 82^{13)}$	2	3.541 ± 0.025	1.459 ± 0.020	320 ± 20	4.619 ± 0.030	$476 \pm 74^{19)}$
⁴⁴ Ca	1.160	$350 \pm 70^{10)}$	2	3.691 ± 0.027	1.428 ± 0.020	480 ± 30	4.704 ± 0.030	$507 \pm 100^{19)}$
			1	3.454 ± 0.025	0.690 ± 0.010	1270 ± 85	5.553 ± 0.030	
⁴⁶ Ti	3.259		2			54 ± 10		
	0.885	$830 \pm 170^{14)}$	2	3.807 ± 0.014	1.397 ± 0.010	740 ± 20	4.763 ± 0.017	$867^{20)}$
		$560 \pm 100^{12)}$	1	3.562 ± 0.014	0.669 ± 0.005	1680 ± 50	5.510 ± 0.020	$738^{11)}$
⁴⁸ Ti	0.984	$700 \pm 140^{14)}$	2	3.777 ± 0.014	1.340 ± 0.010	537 ± 15	4.671 ± 0.017	$788 \pm 120^{19)}$
		$310 \pm 70^{12)}$	1	3.539 ± 0.014	0.633 ± 0.005	1110 ± 30	5.321 ± 0.020	$673^{11)}$
⁵⁰ Ti	2.420		2			49 ± 8		$659^{20)}$
	1.580	$240 \pm 20^{12)}$	2	3.768 ± 0.014	1.255 ± 0.010	307 ± 10	4.567 ± 0.017	$57 \pm 10^{19)}$
			1	3.535 ± 0.014	0.576 ± 0.005	515 ± 17	5.047 ± 0.020	$349^{20)}$ $260^{21)}$
⁵⁶ Fe	4.320		2			51 ± 8		$431^{24)}$
	0.880	$877 \pm 70^{15)}$	2	4.048 ± 0.024	1.357 ± 0.014	945 ± 45	4.919 ± 0.025	$72^{24)}$
			1	3.878 ± 0.024	0.651 ± 0.006	1570 ± 70	5.454 ± 0.030	

Present experiment

*) Errors do not reflect any model dependence.

b) Given errors do not include the 6% error of normalization.

c) Average for $B(E2)$ formed from values of refs. ¹²⁻¹⁸⁾.

13) J. Simpson, J. Cookson, D. Eccleshall and M. Yates, Nucl. Phys. 62 (1965) 385

14) G. M. Temmer and N. P. Heydenburg, Phys. Rev. 104 (1956) 967

15) D. S. Andreyev, A. P. Grinberg, K. I. Erokhina and I. Kh. Lemberg, Nucl. Phys. 19 (1960) 400

16) F. R. Metzger, Nucl. Phys. 27 (1961) 612

17) W. H. Kelly and G. B. Beard, Nucl. Phys. 27 (1961) 188

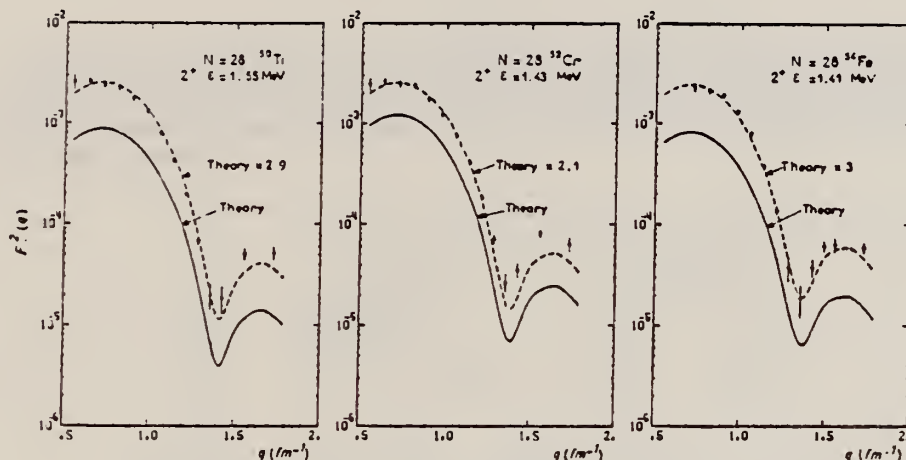
18) R. B. Begzhanov, A. A. Islamov, D. K. Kaipov and Yu. K. Shubnyi, JETP (Sov. Phys.) 17 (1963) 94

ELEM. SYM.	A	Z
Ti	50	22
REF. NO.		egf
73 Ho 4		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1- 5	D	209	MAG-D		DST

1.55, 2.68, 4.40

Fig. 5a. Squared inelastic form factor for 2^+ states of the $N = 28$ isotones.TABLE 2
Inelastic cross sections for $E_n = 209$ MeV on ^{50}Ti

θ (deg.)	$(2^+) \epsilon = 1.55$ MeV $d\sigma/d\Omega$ (mb/sr)	$(3^-) \epsilon = 4.40$ MeV $d\sigma/d\Omega$ (mb/sr)	$(4^+) \epsilon = 2.68$ MeV $d\sigma/d\Omega$ (mb/sr)
30	$0.308 \text{ E-}1 \pm 0.510 \text{ E-}2$		
35	$0.167 \text{ E-}1 \pm 0.130 \text{ E-}2$	$0.376 \text{ E-}2 \pm 0.124 \text{ E-}2$	$0.419 \text{ E-}3 \pm 0.282 \text{ E-}3$
40	$0.904 \text{ E-}2 \pm 0.540 \text{ E-}3$	$0.330 \text{ E-}2 \pm 0.440 \text{ E-}3$	$0.703 \text{ E-}3 \pm 0.364 \text{ E-}3$
45	$0.502 \text{ E-}2 \pm 0.360 \text{ E-}3$	$0.225 \text{ E-}2 \pm 0.160 \text{ E-}3$	$0.451 \text{ E-}3 \pm 0.112 \text{ E-}3$
50	$0.264 \text{ E-}2 \pm 0.160 \text{ E-}3$	$0.163 \text{ E-}2 \pm 0.800 \text{ E-}4$	$0.394 \text{ E-}3 \pm 0.440 \text{ E-}4$
55	$0.131 \text{ E-}2 \pm 0.770 \text{ E-}3$	$0.112 \text{ E-}2 \pm 0.600 \text{ E-}4$	$0.309 \text{ E-}3 \pm 0.250 \text{ E-}4$
60	$0.550 \text{ E-}3 \pm 0.330 \text{ E-}4$	$0.793 \text{ E-}3 \pm 0.410 \text{ E-}4$	$0.231 \text{ E-}3 \pm 0.170 \text{ E-}4$
65	$0.212 \text{ E-}3 \pm 0.110 \text{ E-}4$	$0.468 \text{ E-}3 \pm 0.230 \text{ E-}4$	$0.184 \text{ E-}3 \pm 0.130 \text{ E-}4$
70	$0.710 \text{ E-}4 \pm 0.340 \text{ E-}5$	$0.282 \text{ E-}3 \pm 0.160 \text{ E-}4$	$0.143 \text{ E-}3 \pm 0.100 \text{ E-}4$
75	$0.182 \text{ E-}4 \pm 0.170 \text{ E-}5$	$0.140 \text{ E-}3 \pm 0.700 \text{ E-}5$	$0.925 \text{ E-}4 \pm 0.630 \text{ E-}5$
80	$0.393 \text{ E-}5 \pm 0.108 \text{ E-}5$	$0.805 \text{ E-}4 \pm 0.490 \text{ E-}5$	$0.596 \text{ E-}4 \pm 0.340 \text{ E-}5$
85	$0.277 \text{ E-}5 \pm 0.810 \text{ E-}6$	$0.370 \text{ E-}4 \pm 0.220 \text{ E-}5$	$0.386 \text{ E-}4 \pm 0.270 \text{ E-}5$
95	$0.449 \text{ E-}5 \pm 0.540 \text{ E-}6$	$0.647 \text{ E-}5 \pm 0.111 \text{ E-}5$	$0.130 \text{ E-}4 \pm 0.800 \text{ E-}6$
110	$0.214 \text{ E-}5 \pm 0.310 \text{ E-}6$	$0.881 \text{ E-}6 \pm 0.299 \text{ E-}6$	$0.164 \text{ E-}5 \pm 0.260 \text{ E-}6$

Energy level diagram given by ref. ²⁴). Levels excited in our experiment are shown with solid lines, dashed lines correspond to other levels. The experimental values are normalized on our elastic cross sections considered as reference values.

²⁴ Nuclear Data Sheets B (1970).

(over)

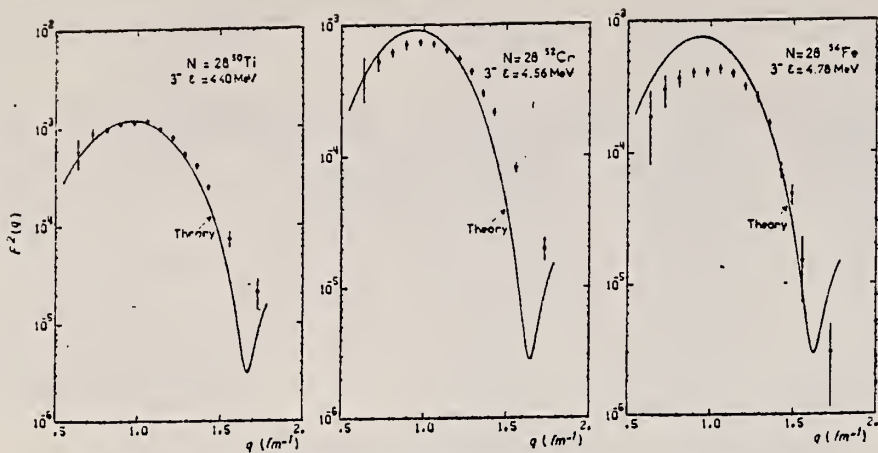


Fig. 6a. Squared inelastic form factor for 3^- states of the $N = 28$ isotones.

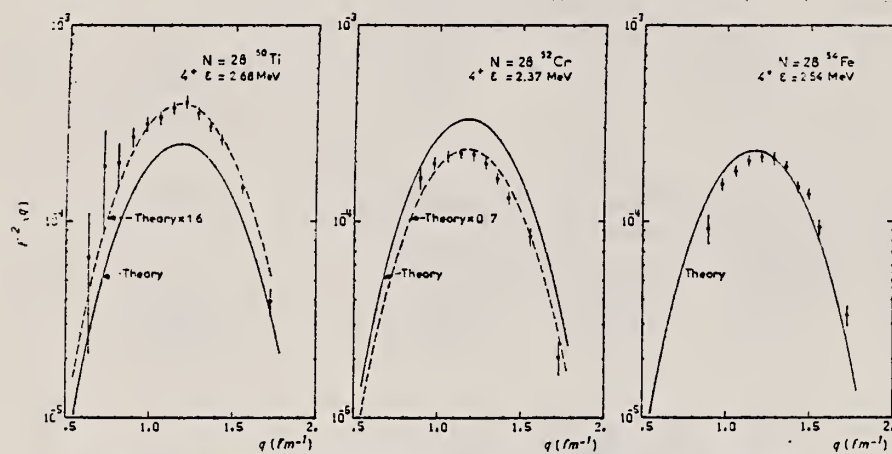


Fig. 7a. Squared inelastic form factor for 4^+ states of the $N = 28$ isotones.

REF. G. Eulenberg, D.I. Sober, W. Steffen, H.-D. Gräf, G. Kuchler,
A. Richter, E. Spamer, B.C. Metsch, W. Knüpfer
Phys. Lett. 116B, 113 (1982)

ELEM. SYM.	A	Z
Ti	50	22

REF. NO.	
82 Eu 1	egf

METHOD				REF. NO.		
				82 Eu 1		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
E,e'/	ABX	8-12	D	30-58	MAG-D	

M1 STRENGTH

Following the recent discovery of a very strong magnetic dipole transition in ^{48}Ca to a state at 10.23 MeV in high-resolution inelastic electron scattering, results of a detailed search for M1 strength in the other $N = 28$ isotones ^{50}Ti , ^{52}Cr and ^{54}Fe are described. The M1 strength found in the investigated region of excitation energy $E_x \approx 7-12$ MeV is very fragmented and considerably quenched in comparison to predictions of shell model calculations in a model space that includes up to $2p-2h$ excitations.

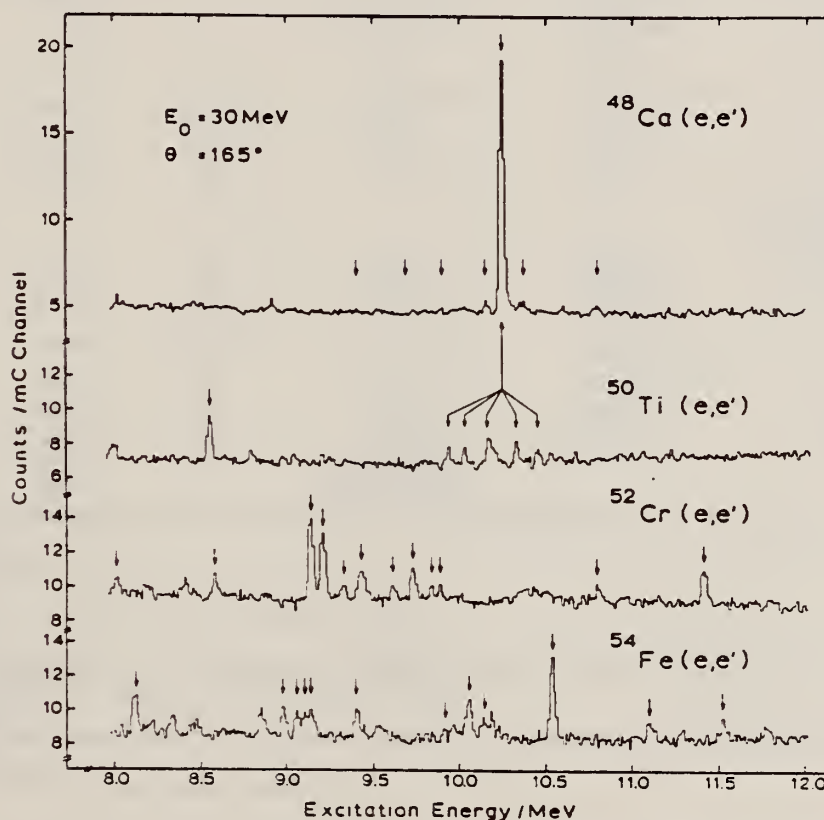


Fig. 1. High-resolution inelastic electron scattering spectra of the $N = 28$ isotones all measured at $E_0 = 30$ MeV and at $\theta = 165^\circ$. The strongest magnetic dipole transitions are indicated by arrows.

(OVER)

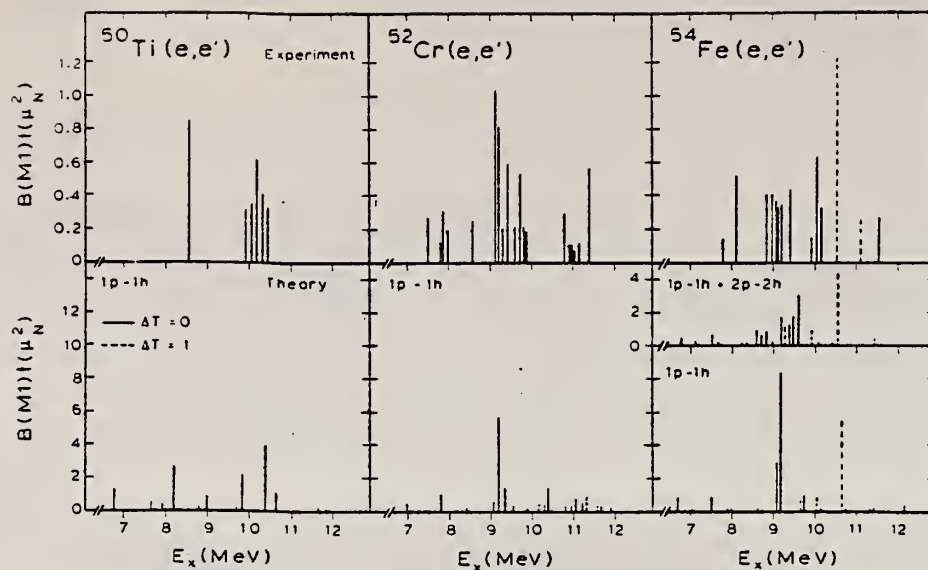


Fig. 3. Comparison of experimental and calculated M1 strength distributions for ^{50}Ti , ^{52}Cr and ^{54}Fe . Note the scale difference. For details, see the main text.

METHOD				REF. NO.	
				76 Ra 1	egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G, G	LFT	1, 5	C	1- 5	DST
		(1.554-4.311)		(1.3-4.7)	

1554,4311 KEV

TABLE II. Mean lives of some levels in the titanium isotopes.

Mass no., ground state, spin, & abund.	Level energy (keV)	Level spin	Γ_0 (meV)	τ (pres. meas.) (fs)	τ (other) (fs)
46, 0 ⁺ 7.95%	3168 4316	1 ⁻ 1	7.3 ± 2.0 (172 ± 26) Γ/Γ_0	41 ± 12 0.96 ± 0.14 ^b	71 ± 12 ^a <44 ^a
47, $\frac{1}{2}$ ⁻ 7.75%	2162 2297	$\frac{1}{2}$ ⁻ ($\frac{1}{2}$ ⁻ , $\frac{1}{2}$ ⁻)	18 ± 5 { 104 ± 10 or ^d 78 ± 8	38 ± 10 4.7 ± 0.5 or ^d 6.3 ± 0.7	31 ± 8 ^c 11 ± 7 ^c
	2548	$\frac{1}{2}$ ⁻	72 ± 8	9 ± 1	
48, 0 ⁺ 73.45%	2421	2 ₂ ⁺	0.74 ± 0.18	44 ± 12	35 ± 7 ^e { $\Gamma_0 = 0.66 \pm 0.11$ meV and 0.77 ± 0.14 ^f
	3371	2 ₃ ⁺	5.5 ± 0.6	16.1 ± 2.1	18 ± 7 ^e
	3700	1 ⁽⁺⁾	20.4 ± 2.3	15.1 ± 1.6	35 ± 3 ^g
	3739	1 ⁺	101 ± 10	4.2 ± 0.4	16 ± 3 ^g
49, $\frac{1}{2}$ ⁻ 5.51%	1623 1763	($\frac{1}{2}$ ⁻ , $\frac{1}{2}$ ⁻ , $\frac{1}{2}$ ⁻) $\frac{1}{2}$ ⁻	11.4 ± 1.5 ^h 18.3 ± 2.2	55 ± 7 36 ± 4.3	
50, 0 ⁺ 5.34% (47, 49)	1554 (4311) 3917 2810	2 ₁ ⁺ 2 ⁺	0.52 ± 0.15 85 ± 60 (90 ± 20) $\Gamma/g\Gamma_0$ ^k (29 ± 4) $\Gamma/g\Gamma_0$ ^k	1300 ± 400 1 < τ < 6	$\Gamma = 0.48 \pm 0.04$ meV ⁱ <80 ^j

^a Reference 11.

^b Assuming $\Gamma_0/\Gamma = 0.50$.

^c Reference 18.

^d The larger width and shorter lifetime correspond to spin $\frac{1}{2}$.

^e Reference 23.

^f Coulomb excitation and (e, e'), J. Heisenberg, J. S. McCarthy, and I. Sick, Nucl. Phys. A164, 353 (1971).

^g C. D. Kavaloski and W. J. Kossler, Phys. Rev. 180, 971 (1969).

^h Assuming spin $\frac{1}{2}$.

ⁱ From Coulomb excitation results of C. W. Towsley, D. Cline, and R. Horoshko, Nucl. Phys. A250, 381 (1975).

^j Reference 12.

^k Calculated as if ⁴⁹Ti, g is the statistical factor.

¹¹ P.A. Assimakopoulos, et al., Nucl. Phys. A180, 131 (1972).

¹² J.G. Pronko et al., Phys. Rev. C10, 1345 (1974).

¹⁸ J.J. Weaver et al., Nucl. Phys. A196, 269 (1972).

²³ T.T. Bardin et al., Phys. Rev. C7, 190 (1973).

ELEM. SYM.	A	Z
Ti	50	22
REF. NO.		
79 Py 6		hg

REACTION		RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
				TYPE	RANGE	TYPE	RANGE	
G,XN		ABX	10-27	C	10-27	BF3-I		4PI
(G,NO)		RLX	10-26	C	15-26	SCI-D		90

Abstract: Measurements of the $^{50}\text{Ti}(\gamma, n)$ and $^{50}\text{Ti}(\gamma, n_0)$ cross sections have been made in the energy range of the giant dipole resonance (GDR). Assuming the GDR is split into two isospin components, approximated as Lorentzians, a calculation based on statistical decay of the GDR states is consistent with the experimental results.

COMMENT: Blatt & Weisskopf statistical model used to obtain $\sigma(\gamma, sn)$ from measured $\sigma(\gamma, xn)$. Sample used was 68.1% ^{50}Ti and about 31.9% ^{48}Ti . Yield curve was corrected using data from second sample enriched in ^{48}Ti .

E NUCLEAR REACTIONS $^{50}\text{Ti}(\gamma, n)$, bremsstrahlung, $E = \text{th-28 MeV}$; measured yield curves, deduced σ . B^{10}F_3 detector. Enriched target. $^{50}\text{Ti}(\gamma, n_0)$, bremsstrahlung, $E = 15.5\text{-}26$ MeV; measured neutron spectra, deduced σ . Stilbene detector. Enriched target.

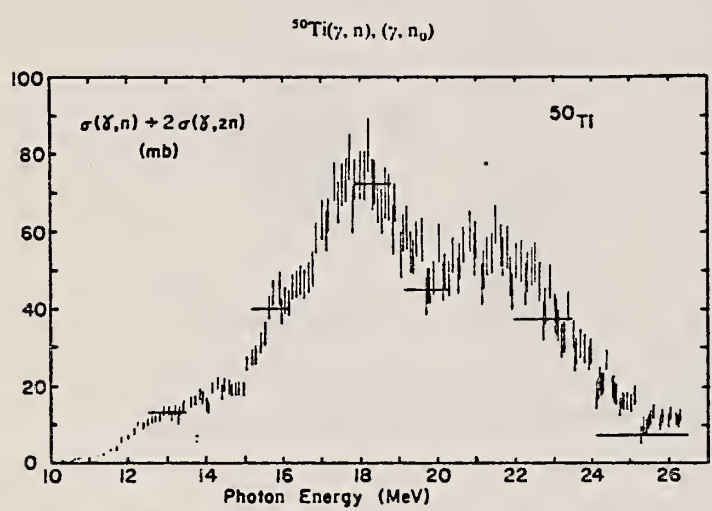


Fig. 2. The $^{50}\text{Ti}[\sigma(\gamma, n) + 2\sigma(\gamma, 2n)]$ cross section derived using the VBPL technique. Vertical error bars are statistical only. There is a 10% uncertainty in the absolute cross section scale. Horizontal bars show the analysis bin width used.

(OVER)

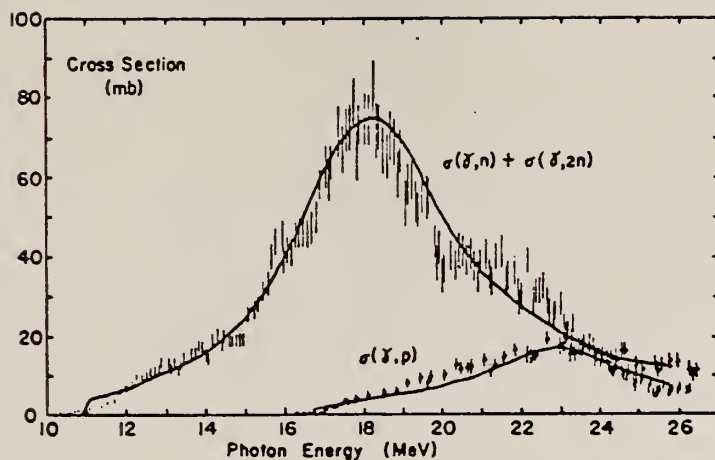


Fig. 3. Error bars only show the $^{50}\text{Ti}[\sigma(\gamma, n) + \sigma(\gamma, 2n)]$ cross section after correction for the double counting of the $(\gamma, 2n)$ cross section using a statistical model. Solid dots with error bars show the $^{50}\text{Ti}(\gamma, p)$ cross section from ref. ¹³. Solid lines are the calculated (γ, n) and (γ, p) cross sections as described in the text.

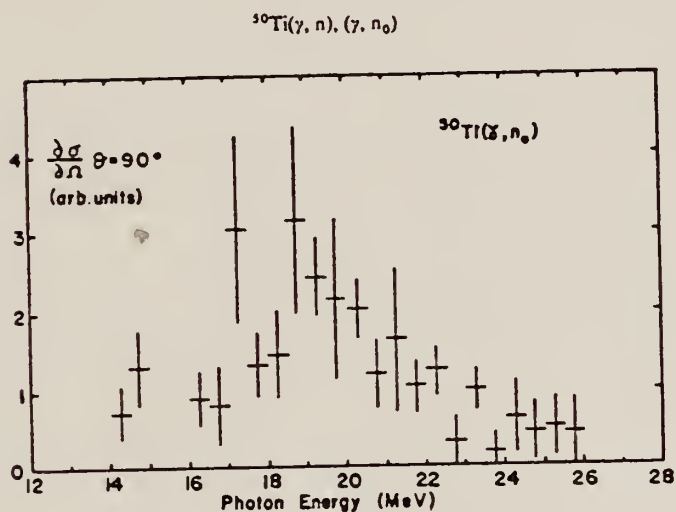


Fig. 5. The derived $^{50}\text{Ti}(\gamma, n_0)$ differential cross section at $\theta = 90^\circ$. Cross section scale is arbitrary.

T_1
A=52

T_1
A=52

T_1
A=52

REF.

ELEM. SYM.	A	Z
Ti	52	22

METHOD	REF. NO.	
	74 Pe 3	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
A, G	ABX	13- 20	D	6- 14	NAI-D		90

$d\sigma/d\Omega(90^\circ)$ measured

The isospin allowed reaction $^{48}\text{Ca}(\alpha, \gamma)^{52}\text{Ti}$ was investigated in the α -particle energy range from 6.0-14.0 MeV, corresponding to 12.7-20.4 MeV excitation energy in ^{52}Ti (taking into account the target thickness). The intense low energy background made possible only the study of the $^{48}\text{Ca}(\alpha, \gamma_0)^{52}\text{Ti}$ reaction. Fig. 8 shows the γ -radiation spectrum obtained at the maximum of the 90° differential cross section in the region studied. The differential cross section extracted from this spectrum gives

$$d\sigma/d\Omega(90^\circ) = 45 \pm 8 \text{ nb/sr}, \quad E_\alpha^{\text{lab}} = 7.00 \text{ MeV}.$$

For the remainder of the energy region studied, only an upper limit on the 90° differential cross section was obtained,

$$d\sigma/d\Omega(90^\circ) < 30 \text{ nb/sr}.$$

The $^{12}\text{C}(\alpha, \gamma_0)^{16}\text{O}$ reaction was used to check both the energy calibration and the γ -spectrometer immediately following the $^{48}\text{Ca}(\alpha, \gamma)^{52}\text{Ti}$ investigation. Because of the extremely low cross section of the $^{48}\text{Ca}(\alpha, \gamma)^{52}\text{Ti}$ reaction, no angular distribution measurements were attempted.

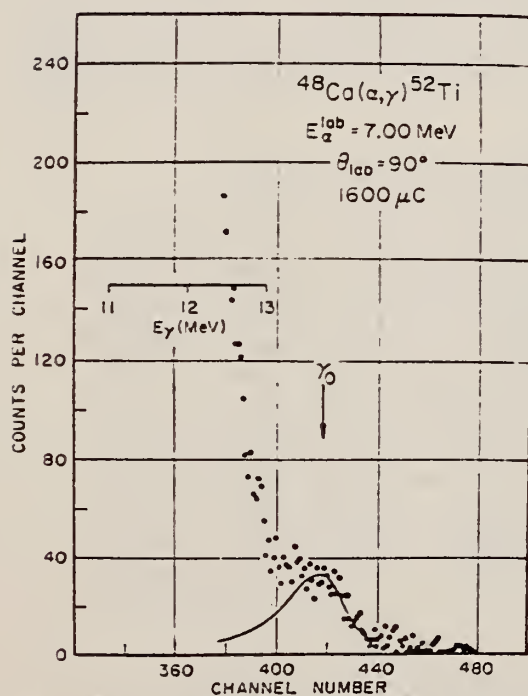


Fig. 8. The γ -radiation spectrum for the reaction $^{48}\text{Ca}(\alpha, \gamma)^{52}\text{Ti}$ at $E_\alpha^{\text{lab}} = 7.0 \text{ MeV}$. A background subtraction for the residual cosmic radiation has been performed. Only the ground state transition was observed. From the systematics of the first excited state in doubly even Ti nuclei, the γ_1 transition would appear below channel 400.

VANADIUM
Z=23

Andrés Manuel del Río in 1801, discovered a new element in vanadinite from Zimapán, Mexico. A few years later he decided he was mistaken and that the brown ore was merely a basic lead chromate. In 1805 Collet-Descotils confirmed del Río's analysis and for twenty-five years no more was heard of the new element.

In 1830, N. G. Sefström discovered a new element in iron from the Taberg mine in Smaland. He named it vanadium, from Vanadis, the Scandinavian goddess of beauty and youth— a name suggested by the beautiful colors of its compounds in solution. Just before this, F. Wöhler had reexamined the vanadinite ore from Zimapán and found that the new element surmised and abandoned by Del Río was identical with the vanadium of Sefström. Wöhler failed to report his findings because of an illness due to poisoning by hydrogen fluoride vapor. In a charming letter to Wöhler, Berzelius wrote:

V
A=49

In regard to the sample which I am sending with this, I want to tell the following anecdote: In the far north there lived in olden times the goddess Vanadis, beautiful and lovable. One day some one knocked at her door. The goddess remained comfortably seated and thought: let the person knock again; but there was no more knocking, and the one who had knocked went down the steps. The goddess was curious to see who it might be that was so indifferent to being admitted, sprang to the window, and looked at the one who was going away. Alas! she said to herself, that's that fellow Wöhler. Well, he surely deserved it; if he had been a little more concerned about it, he would have been admitted. The fellow does not look up to the window once in passing by....

After a few days some one knocked again at the door; but this time the knocking continued. The goddess finally came herself and opened the door. Sefström entered, and from this union vanadium was born.

REF. I. Fodor, I. Demeter, L. Keszthelyi, I. Szentpetery,
Z. Szokefalvi-Nagy, J. Szucs, L. Varga and J. Zimanyi
Nucl. Phys. A116, 167 (1968)

ELEM. SYM.	A	Z
V	49	23
REF. NO.		egf
68 Fo 1		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
P,G	LFT	8	D	1	SCD-D	0-8	DST

ANALOG STATE

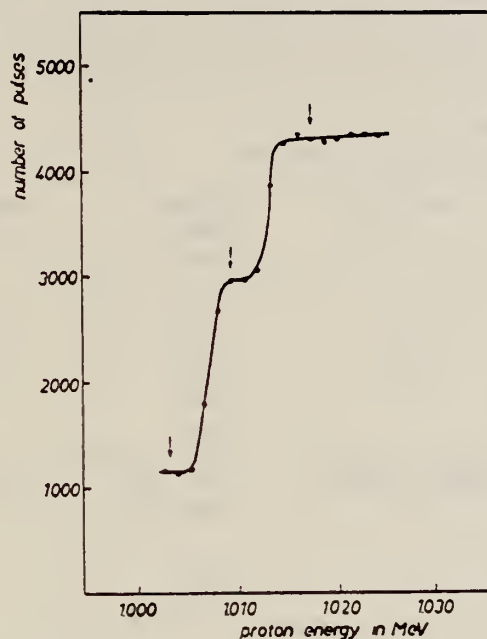


Fig. 5. Excitation function of the 1.007 and 1.013 MeV resonances in the $^{46}\text{Ti}(p,\gamma)^{46}\text{V}$ reaction on the "quasi-thick" target.

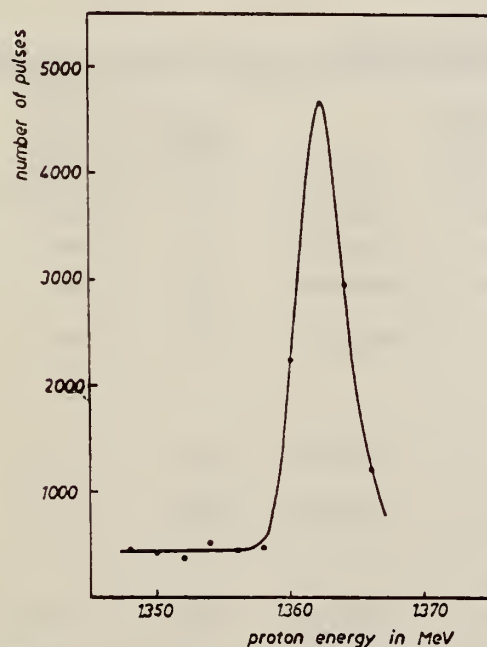


Fig. 6. Excitation function of the 1.362 MeV resonance in the $^{46}\text{Ti}(p,\gamma)^{46}\text{V}$ reaction.

[over]

TABLE 2
 γ -transitions, relative intensities and absolute widths in ^{49}V

Energy of resonant level(MeV)	Spin and parity	Transitions into states		Relative intensity	Multipolarity	Measured widths (eV)	Weiskopf estimate (eV)
		E(keV)	J, π				
7.735	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	<6			
		90.6	$\frac{1}{2}^-$	113	M1	0.15	9.56
		153	$\frac{1}{2}^-$	100	M1	0.13	9.25
		1633		30		0.04	
		1648		20		0.03	
7.741	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	<9	0.998M1+0.002E2	0.22 M1	9.6
		90.6	$\frac{1}{2}^-$	100		0.0004 E2	0.23
		153	$\frac{1}{2}^-$	<9			
		1633		30		0.07	
		1648		7		0.02	
8.088	$\frac{1}{2}^-$	0	$\frac{1}{2}^-$	<5			
		90.6	$\frac{1}{2}^-$	<7			
		153	$\frac{1}{2}^-$	100	M1	1.7	10.6
		1633		3			
		1648		4			

REF. J.C. Legg, D.G. Megli, D.R. Abraham, L.D. Ellsworth, and S. Hecht1
Phys. Rev. 186, 1138 (1969)

ELEM. SYM.	A	Z
V	49	23
REF. NO.		
69 Le 1		egf

METHOD					REF. NO.	
					69 Le 1	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
P,G	LFT	7-8	D	1-2	SCD-D	

4 LEVELS

TABLE I (Continued)

Proton resonance energy (keV)	Primary γ -ray energy (keV)	Final-state energy (keV)	A_2/A_0	Radiative width (eV)	Radiative width in Weisskopf units*	J_i^π	J_f^π	Mixing ratio λ
1387	8022	89	-0.27 ± 0.17	0.009	0.0005	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.11 ± 0.15
	7962	152	0.00 ± 0.05	0.05	0.025	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.26 ± 0.03
	7366	747	0.375 ± 0.079	0.03	0.0004	$\frac{1}{2}^-$	$\frac{3}{2}^+$	0.01 ± 0.05 -4.07 ± 0.80
	6977	1138	0.028 ± 0.085	0.03	0.002	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.11 ± 0.08 3.0 ± 0.7
					0.2	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.12 ± 0.08 1.9 ± 0.4
	6472	1639	-0.15 ± 0.11	0.02	0.00006	$\frac{1}{2}^-$	$\frac{1}{2}^+$	-0.19 ± 0.06 2.9 ± 0.5
	6454	1658	-0.04 ± 0.12	0.02	0.004	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.25 ± 0.06 3.5 ± 0.6
					0.020	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.28 ± 0.09 41 ± 31
	6125	1990	-0.17 ± 0.06	0.05	0.0002	$\frac{1}{2}^-$	$\frac{3}{2}^+$	-0.18 ± 0.03 2.9 ± 0.3

* V. F. Weisskopf, Phys. Rev. 83, 1073 (1951).

[over]

TABLE I. γ decay of resonances.

Proton resonance energy (keV)	Primary γ -ray energy (keV)	Final-state energy (keV)	A_2/A_0	Radiative width (eV)	Radiative width in Weisskopf units ^a	J_i^π	J_f^π	Mixing ratio δ
1007	7653	89	0.043 ± 0.035	0.11	0.007	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.13 ± 0.03 2.84 ± 0.29
	7591	152	0.469 ± 0.028	0.15	0.08	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.05 ± 0.02 -3.25 ± 0.23
	6101	1639	-0.426 ± 0.064	0.05	0.0002	$\frac{1}{2}^-$	$\frac{3}{2}^+$	-0.038 ± 0.035 1.91 ± 0.17
	6086	1658	0.04 ± 0.06	0.05	0.01	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.29 ± 0.03 4.04 ± 0.54
					0.05	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.23 ± 0.04 -33.7 ± 19.4
	5504	2237	-0.68 ± 0.28	0.01		$\frac{1}{2}^-$	$\frac{1}{2}$	0.11 ± 0.23 1.37 ± 0.60
							$\frac{1}{2}$	No solution
							$\frac{1}{2}$	-0.28 ± 0.33 -3.08 ± 1.9
	5438	2303	0.403 ± 0.103	0.03	0.01	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.51 ± 0.07 19.1 ± 9.6
					0.05	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.00 ± 0.07 -3.87 ± 0.95
1013	7748	0	0.17 ± 0.27	0.007	0.01	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.03 ± 0.38 1.35 ± 0.90
	7658	89	-0.030 ± 0.20	0.17	0.01	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.058 ± 0.019 3.61 ± 0.28
	7597	152	0.58 ± 0.23	0.009	0.005	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.13 ± 0.15 -2.51 ± 0.95
	7002	747	0.4 ± 0.4	0.005	0.0001	$\frac{1}{2}^-$	$\frac{3}{2}^+$	-0.07 ± 0.27 -3.02 ± 1.45
	6238	1510	-0.03 ± 0.20	0.01		$\frac{1}{2}^-$	$\frac{1}{2}$	-0.25 ± 0.11 3.5 ± 1.0
							$\frac{1}{2}$	0.28 ± 0.15 40 ± 35
							$\frac{1}{2}$	0.06 ± 0.18 3.6 ± 1.6
	6110	1639	-0.469 ± 0.043	0.06	0.0003	$\frac{1}{2}^-$	$\frac{3}{2}^+$	-0.02 ± 0.03 1.80 ± 0.10
	6093	1658	-0.069 ± 0.093	0.02	0.004	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.22 ± 0.05 3.19 ± 0.44
					0.02	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.32 ± 0.07 16.4 ± 8.3
1361	5445	2303	0.25 ± 0.10	0.03	0.009	$\frac{1}{2}^-$	$\frac{1}{2}^-$	-0.41 ± 0.06 7.1 ± 2.0
					0.045	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0.09 ± 0.06 -6.2 ± 1.8
	7935	152	-0.008 ± 0.010	1.4	0.065	$\frac{1}{2}^-$	$\frac{1}{2}^-$	
	6451	1639	-0.08 ± 0.06	0.17	0.0007	$\frac{1}{2}^-$	$\frac{3}{2}^+$	
	6432	1658	...	<0.02		$\frac{1}{2}^-$	$\frac{1}{2}, \frac{3}{2}^-$	

V
A=51

V
A=51

V
A=51

METHOD					REF. NO.	
					56 He 2	EGF
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,A	RLY	THR - 31	C	31	ACT-I	
G,2P	RLY	THR - 31	C	31	ACT-I	

Yield measured relative to (γ, n) yield in ^{63}Cu .

31 MeV bremsstrahlung yields

$$\frac{{}^{51}\text{V}(\gamma, a)}{{}^{63}\text{Cu}(\gamma, n)} = (7 \pm 2) \times 10^{-3}$$

$$\frac{{}^{51}\text{V}(\gamma, 2p)}{{}^{51}\text{V}(\gamma, a)} = 1.9 \times 10^{-2}$$

Ref. P. Erdos, P. Scherrer, P. Stoll
 Helva. Phys. Acta 30, 639 (1957)

Elem. Sym.	A	Z
V	51	23

Method	Ref. No.
Betatron; α yield; radioactivity; $\text{Cu}^{65}(\gamma, n)$ reaction	57 Er 1 EGF

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{V}^{51}(\gamma, \alpha)$	Bremss. 32			5.5 ± 2 MeV-mb		Based on yield measurement.

ELEM. SYM.	A	Z
V	51	23
REF. NO.		
58 Ch 2		NVB

Betatron

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, N	RLY	THR	C	THR	BF ₃ -I		4PI

See 58 Ka 1 for cross sections

THRESHOLD

TABLE I
 MEASURED PHOTON-NEUTRON THRESHOLDS

Reaction	Measured Q value, Mev.	Other Q values, Mev.	Method	Reference
$V^{14}(\gamma, n)V^{14}$	11.16 ± 0.05	11.15 ± 0.20	Threshold	Sher <i>et al.</i> (1951)
		11.24 ± 0.23	Mass data	Wapstra (1955)
		11.05 ± 0.12	Mass data	Duckworth (unpublished)

REF.

A. Halsteinslid, K. Nybo and R. B. Mollerud
 Univ. Bergen Arb. Naturv. R. Nr. 15, 1 (1958)

ELEM. SYM.

A

Z

V

51

23

METHOD

[Page 1 of 2]

REF. NO.

58 Ha 1

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XP	SPC	THR - 30	C	30	EMU-D	2 - 20	DST

$$I(\theta) = a + b \sin^2\theta (1 + p \cos^2\theta)^2$$

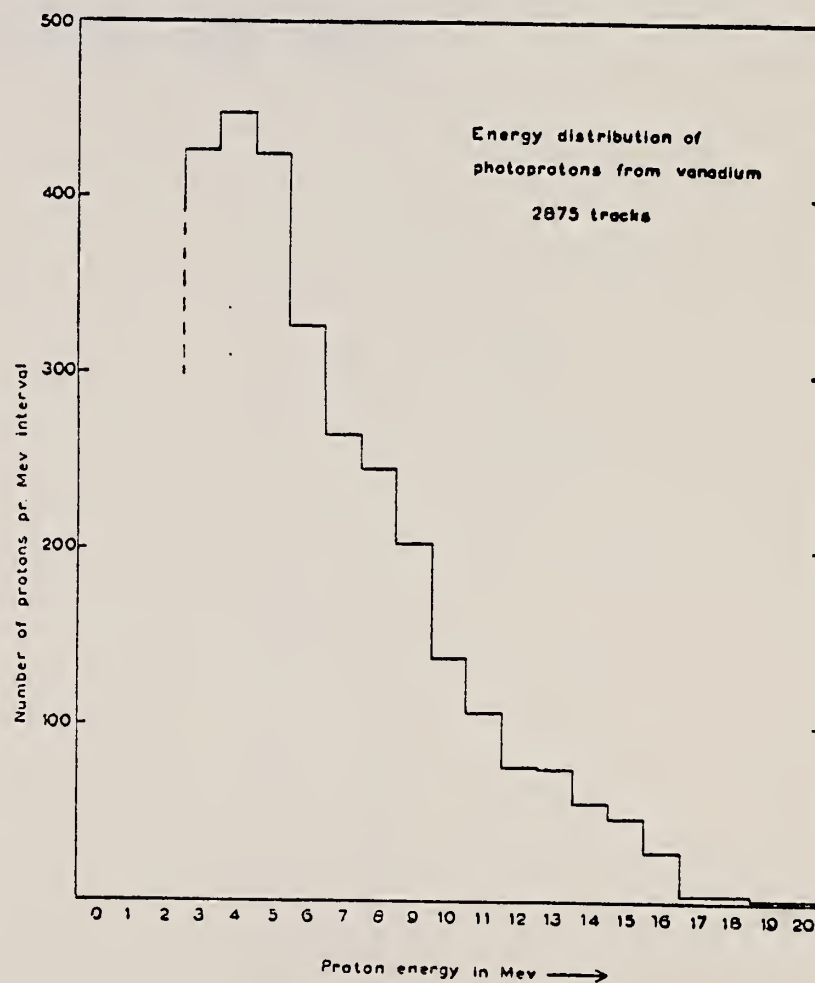


Fig. 3. Energy distribution of photoprotons per Mev-interval, corrected for energy loss in the target.

METHOD

[Page 2 of 2]

REF. NO.

58 Ha 1

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

Table

Proton energy E_p	b/a	p	$\sigma q/\sigma d$
$0 < E_p \leq 10 \text{ Mev}$	$0,5 \pm 0,1$	$0,6 \pm 0,2$	$0,07 \pm 0,03$
$10 \text{ Mev} < E_p$	$1,5 \pm 1,3$	$0,25 \pm 0,2$	$0,01 \pm 0,03$ $0,01$

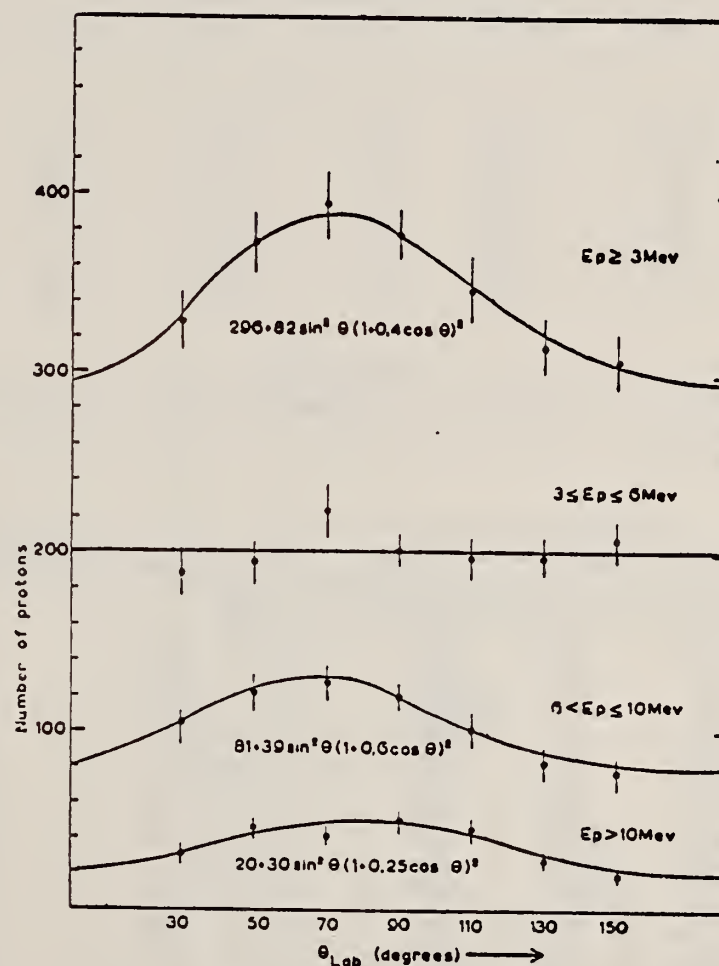


Fig. 4. Angular distribution of photoprotons of various energies, corrected for energy loss in the target.

L. Katz, G.B. Chidley Nuclear Reactions at Low and Medium Energies (Academy of Science, USSR: 1958) 371				V	51	23
METHOD Betatron; neutron cross section; BF ₃ counters; ion chamber monitor				REF. NO. 58 Ka 1		NVB
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G, XN	ABX	12-22	C	12-22	BF ₃ -I	4PI

Таблица 2

Пороги испускания фотонейтронов

Изотоп	B_n , Мэв	$B_{n\gamma}$, Мэв	Изотоп	B_n , Мэв	$B_{n\gamma}$, Мэв
V ⁵¹	11,16	20,5	La ¹³⁹	8,81	16,1
Mn ⁵⁵	10,14	19,2	Pr ¹⁴¹	9,46	17,6
Co ⁵⁹	10,44	18,6	Tb ¹⁵⁹	8,16	14,8
As ⁷⁵	10,24	18,1	Ho ¹⁶⁵	8,10	14,6
Y ⁸⁹	11,82	20,7	Tm ¹⁶⁹	8,00	14,7
Nb ⁹³	8,86	17,1	Lu ¹⁷⁵	7,77	14,2
Rh ¹⁰³	9,46	16,8	Ta ¹⁸¹	7,66	13,8
J ¹²⁷	9,14	16,2	Au ¹⁹⁷	7,96	13,3
Cs ¹³³	9,11	16,5	Bi ²⁰⁹	7,43	14,5

THRESHOLDS

не приведены, поскольку они превышают 22 Мэв во всех случаях, кроме золота, для которого $B_{2n}=21$ Мэв. Свойства сечений $\sigma_C(\gamma)$ сведены в табл. 3.

Таблица 1

Изотоп	$E_{\text{макс}}$, Мэв	$\sigma_n(E_\gamma)$, барн	Γ , Мэв	Γ^{12} , Мэв · барн	$\gamma(22)$, 10 ⁶ нейтрон/100 р · моль
V ⁵¹	18,4	0,062	5,2	0,33	1,62
Mn ⁵⁵	20,2	0,060	7,0	0,39	2,01
Co ⁵⁹	18,3	0,068	6,3	0,44	2,30
As ⁷⁵	16,4	0,090	9,5	0,74	4,25
Y ⁸⁹	17,1	0,172	5,2	0,93	5,33
Nb ⁹³	18,0	0,156	7,5	1,17	6,80
Rh ¹⁰³	17,5	0,160	9,4	1,40	8,28
J ¹²⁷	15,2	0,273	6,8	1,76	11,9
Cs ¹³³	16,5	0,238	7,7	1,59	10,7
La ¹³⁹	15,5	0,325	3,8	1,55	11,2
Pr ¹⁴¹	15,0	0,320	4,9	1,93	13,1
Tb ¹⁵⁹	15,6	0,274	9,8	2,49	18,1
Ho ¹⁶⁵	13,5	0,305	8,9	2,52	18,7
Tm ¹⁶⁹	16,4	0,250	8,4	1,91	14,9
Lu ¹⁷⁵	16,0	0,225	8,4	1,90	23,0
Ta ¹⁸¹	14,5	0,380	8,5	3,15	22,0
Au ¹⁹⁷	13,8	0,475	4,7	3,04	22,6
Bi ²⁰⁹	13,2	0,455	5,9	2,89	23,2

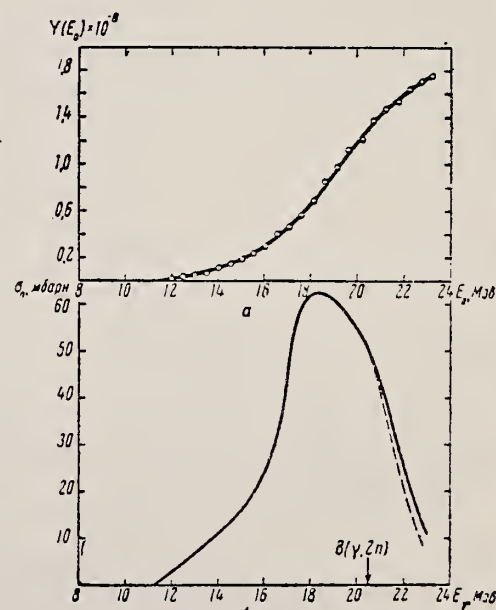


Рис. 1.

α — Выход фотонейтронов для V;
 δ — $\sigma_n(E_\gamma)$ и $\sigma_C(\gamma)$ для V

Method Betatron; alpha yield; nuclear emulsion

Ref. No.	NVB
58 To 2	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$V(\gamma, \alpha)$	Bremss. 22					Yield = 0.4×10^4 alpha/mole/roentgen

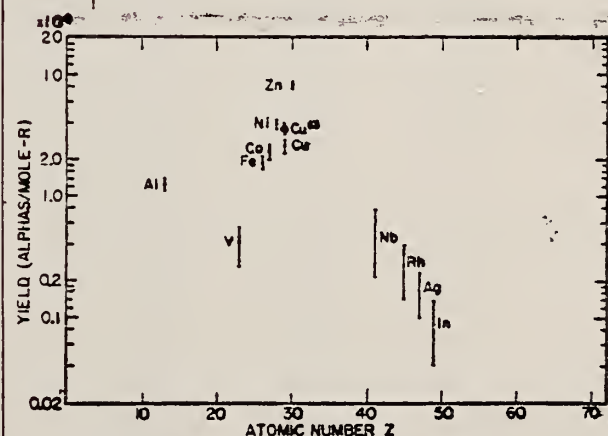


FIG. 8. Photo-alpha yields plotted against atomic numbers for the exposures of the survey.

Elem. Sym.	A	Z
V	51	23
Ref. No. 59 Dy 1		JHH

Method
Betatron; activation, Victoreen r-thimble monitor

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$V^{51}(\gamma, \alpha)$	Bremss. 10.5-25	23		$\int_0^{24.5} = 4.3 \pm 0.4$ MeV-mb		$\sigma_{\max}(E = 23 \text{ MeV}) = 0.81 \text{ mb.}$

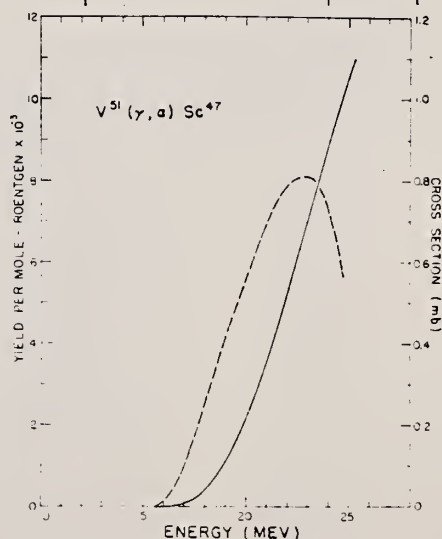


FIG. 1. Solid line - yield curve for the $V^{51}(\gamma, \alpha)Sc^{47}$ reaction - use scale on left; abscissa is the betatron operating energy. Dashed line - cross sections for the $V^{51}(\gamma, \alpha)Sc^{47}$ reaction - use scale on right; abscissa is the gamma-ray energy.

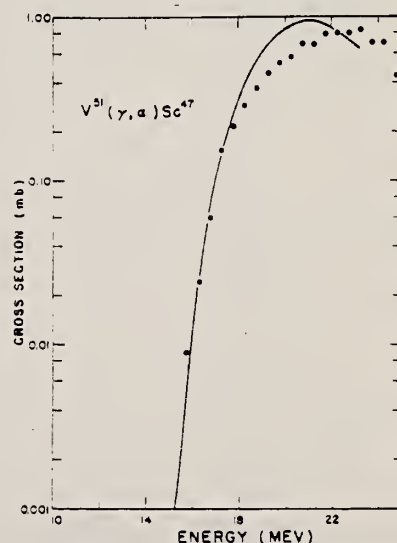


FIG. 2. Comparison of observed and theoretical cross sections for the $V^{51}(\gamma, \alpha)Sc^{47}$ reaction. The solid line represents the theoretical excitation function, and the points are the experimental cross sections derived from the yield curve by the photon difference method.

METHOD				REF. NO.	
Betatron; neutron threshold; ion chamber				60 Ge 3	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,N	NØX	THR	C	THR	4 PI

THRESHOLD

TABLE I. Summary and comparison of neutron separation energies inferred from present threshold measurements with values predicted from mass data and reaction energies. All energies are expressed in the center-of-mass system in Mev.

Reaction	No. runs	Present results	Other results	Method	Reference
$V^{238}(\gamma, n)V^{237}$	1	11.04 ± 0.06	11.040 ± 0.004 11.16 ± 0.05	mass data threshold	$\frac{g}{f}$

[†] See reference 4.
[‡] C. F. Giese and J. L. Benson, Phys. Rev. 110, 712 (1958).

Elem. Sym.	A	Z
V	51	23
Ref. No. 60 Re 1		JHH

Method γ 's from F^{19} (p, γ) reaction; protons from VandeGraaff; NaI.

Ref. No.	
60 Re 1	JHH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(7,7)	$E_\gamma \sim 7 \text{ MeV}$					$\langle \sigma \rangle (E_p = 2.05 \text{ MeV}) = 0.65 \pm .10 \text{ mb}$

METHOD						REF. NO.	
Betatron; fast neutron yield, angular distribution; Si threshold detector; ion chamber						61 Ba 2	
						NVB	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABY	THR-22	C	22	THR-I	5-+	DST

In Table 4:

$\bar{\sigma}$ = average cross section of detector
 weighted with neutron spectrum

$\bar{\phi}$ = neutrons/100 roentgen/mole

$$W(\theta) = a_0 \sum_{n=1}^{\infty} [1 + A_n P_n(\cos \theta)]$$

TABLE IV

I Element	II a_0	III a_1	IV a_2	V $(\bar{\sigma}\phi) \times 10^{10}$	VI $\phi_{\text{total}} (22 \text{ Mev}) \times 10^9$	VII $\phi_{\text{fast}}/\phi_{\text{total}}$
Vanadium	245 (1±0.06)	0.01±0.08	-0.00±0.10	6.05	0.21	0.12
Chromium	164 (1±0.03)	0.04±0.04	-0.05±0.05	4.05	0.17	0.10
Manganese	308 (1±0.02)	0.07±0.03	-0.09±0.04	7.61	0.25	0.12
Iron	200 (1±0.03)	0.05±0.04	-0.17±0.05	4.94	0.18	0.11
Cobalt	390 (1±0.02)	0.08±0.03	-0.22±0.04	9.63	0.26	0.15
Nickel	145 (1±0.05)	0.07±0.07	-0.23±0.09	3.58	0.12	0.12
Copper	347 (1±0.02)	0.05±0.03	-0.29±0.04	8.57	0.30	0.12
Arsenic	482 (1±0.03)	0.11±0.04	-0.24±0.05	11.91	0.33	0.15
Rubidium	638 (1±0.05)	0.13±0.06	-0.14±0.08	15.76		
Strontium	409 (1±0.05)	0.10±0.06	-0.17±0.08	10.10		
Yttrium	290 (1±0.10)	0.08±0.12	-0.12±0.15	7.16		
Silver	590 (1±0.04)	0.10±0.06	-0.22±0.03	14.57	0.87	0.07
Cadmium	905 (1±0.02)	0.02±0.02	-0.26±0.03	22.35		
Iodine	1133 (1±0.03)	0.04±0.04	-0.29±0.05	27.99	1.42	0.08
Barium	1048 (1±0.04)	0.10±0.08	-0.38±0.08	25.89		
Lanthanum	1595 (1±0.02)	0.02±0.03	-0.42±0.04	39.40	1.04	0.15
Cerium	1316 (1±0.05)	0.05±0.06	-0.39±0.08	32.50		
Dysprosium	1652 (1±0.08)	0.04±0.10	-0.34±0.13	40.80		
Tantalum	1558 (1±0.02)	0.04±0.03	-0.22±0.04	38.48	2.50	0.06
Tungsten	1365 (1±0.02)	-0.07±0.03	-0.24±0.04	33.71		
Mercury	1345 (1±0.02)	0.04±0.03	-0.31±0.04	33.22		
Lead	2274 (1±0.01)	0.02±0.02	-0.42±0.03	56.17	2.72	0.08
Bismuth	2162 (1±0.02)	0.05±0.03	-0.45±0.04	53.40	3.36	0.06
Thorium	3031 (1±0.04)	0.06±0.05	-0.32±0.07	74.87		
Uranium	4630 (1±0.02)	0.05±0.03	-0.17±0.04	114.36		

* $(\bar{\sigma}\phi) = 2.47 \times 10^7$ mb-millibarn-neutron. Errors are standard errors due to counting statistics only.

METHOD Synchrotron; alpha cross section; Radioactivity

REF. NO.

61 Ca 2

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, A	ABX	THR-32	C	THR-32	ACT- I		4PI

742

$$\sigma_{\text{peak}} = 0.95 \text{ mb}$$

$$E_{\text{peak}} = 22 \text{ MeV}$$

$$\int_0^{32} \sigma dE = 12 \pm 2 \text{ MeV-mb}$$

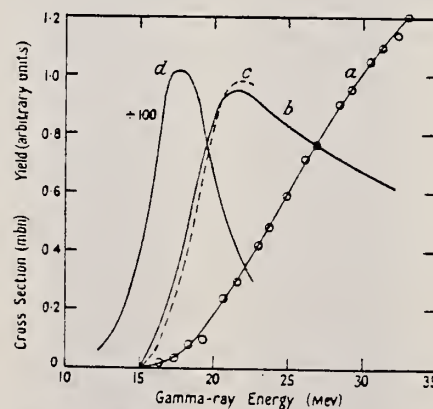


Fig. 3. *a*, activation curve for the $^{51}\text{V}(\gamma, \alpha)^{47}\text{Sc}$ reaction; *b*, the derived $^{51}\text{V}(\gamma, \alpha)$ cross section; *c*, the $^{51}\text{V}(\gamma, \alpha)$ cross section calculated by means of the statistical theory; *d*, the $^{51}\text{V}(\gamma, n)$ cross section of Goldemberg and Katz (1954) used in the calculation of curve *c*. (Note difference in cross section scale for curve *d*.)

Elem. Sym.	A	Z
V	51	23
Ref. No.	62Fu1	BG

Method

 e^+ annihilation - ion chamber, BF_3

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(γ, n)	8.5 - 28	18.25	6	$.451 \pm .045$	28_0	$(\gamma, 2n)$ threshold = 20.25 ± 0.3 MeV It is estimated (γ, p) reaction would contribute 22% to formation cross section, i.e. $\int [\sigma(\gamma, n) + \sigma(\gamma, 2n) + \sigma(\gamma, np) + \sigma(\gamma, p)] dE = .68$ MeVb $\sigma_{-2} = \int_0^{28} \sigma(E) E^{-2} dE = 1.56 \text{ mb-MeV}^{-1}$ $Q_0 = .66 \pm 0.09b$
$(\gamma, 2n)$	(443)	23.75		$.106 \pm .011$	28_0	
$(\gamma, n) + (\gamma, 2n)$				$.557 \pm .056$	28_0	
$+ (\gamma, np)$						

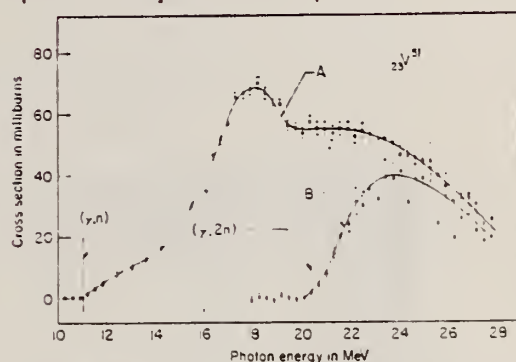


FIG. 4. Cross sections for V from neutron yield data. Curve A consists of $\sigma(\gamma, n) + 2\sigma(\gamma, 2n) + \sigma(\gamma, np) + 3\sigma(\gamma, 3n)$ and was obtained from single-neutron counting data. Curve B consists of $2\sigma(\gamma, 2n) + 6\sigma(\gamma, 3n)$ and was obtained from double-neutron counting data.

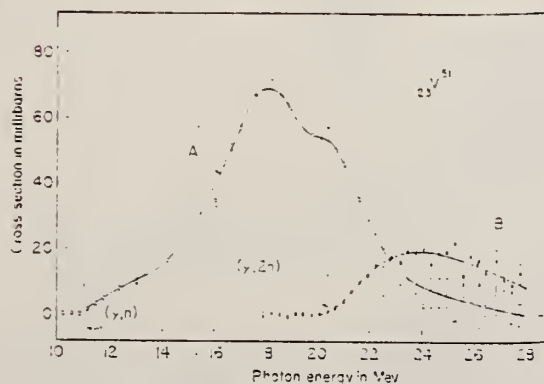


FIG. 5. Partial cross-section curves for V. Curve A consists of $\sigma(\gamma, n) + \sigma(\gamma, np)$. Curve B consists of $\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n)$.

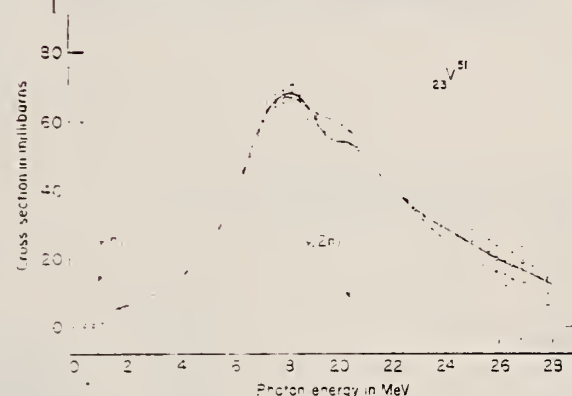


FIG. 6. The formation cross section $\sigma(\gamma, n) + \sigma(\gamma, 2n) + \sigma(\gamma, np)$ for the compound nucleus V^{41} . The solid curve represents an average line through the data points. The dashed curve is the sum of two Lorentz lines with parameters given in Table I.

TABLE I. Lorentz line and nuclear shape parameters for Co and V.

Element	E_0 (MeV)	Γ (MeV)	E_1 (MeV)	Γ_1 (MeV)	E_2 (MeV)	Q_0 (b)	β (10 ⁻³ cm)	β_1 (10 ⁻³ cm)	β_2 (10 ⁻³ cm)
Co ⁶⁰	40	3.75	19.5	43.4	7.0	19.25	0.94	5.53	4.68
V ⁵¹	41	3.50	17.5	46	6.5	20.25	0.66	4.40	5.13

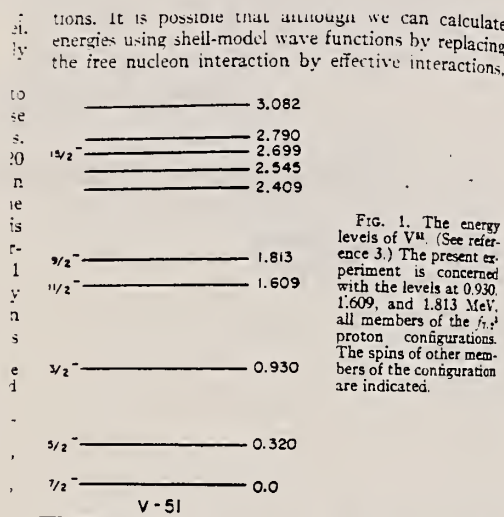
TABLE II. Integrated cross sections and nuclear level density parameters. σ_{tot} includes estimated contributions for (γ, p) reactions.

Element	σ_{tot} (mb/MeV)	$\sigma_{(n,2n)}$ (mb/MeV)	$\sigma_{(n,np)}$ (mb/MeV)	$\int_0^{28} \sigma dE$ (MeV-b)	$\int_0^{28} \sigma E^{-1} dE$ (MeV ⁻¹ -b)	$\sigma_{(n,2n)}$ (MeV-b)
Co ⁶⁰	1.42	2.014	5.49	0.336	0.97	0.870
V ⁵¹	1.56	1.104	6.13	0.337	0.94	0.738

Elem. Sym.	A	Z
V	51	23
Ref. No.	62Ke1	
	B 6	

Method	Stanford MKIII accelerator - counter telescope				
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Reaction	E or ΔE	E ₀	Γ	∫σdE	Jπ	Notes
(e,e')	183,300 600	0.930 1.609, 1.813 also see Fig. 1			see Fig. 1	1.609 and 1.813 MeV levels were not completely resolved in any of the runs. Levels calculated from pure shell model $f_{7/2}^3$ configuration and effective two-body forces taken from $f_{7/2}^3$ configurations agree well with measured low-lying energy levels. E2 transition rates between good shell-model $f_{7/2}^3$ states are strongly enhanced. $B(E2)$ proportional to E2 transition rate. 2 are strength parameters. m = measured transition rates to ground states.



See J. E. Schwager, Phys. Rev. 121, 569 (1961) for the most recent experimental results and for a number of references on shell-model calculations.

Table II. Experimental values of $B(E2)$, Γ_{α} , $B(E2)$, and G . The table gives the electron scattering results for transitions in V^{51} . The α are the transition energies. The uncertainties in the $B(E2)$ are standard deviations from counting statistics and from uncertainties in the α parameter required in the predicted $B(E2)$. These uncertainties are indicated in Γ_{α} , the gamma-ray decay rates, in the reduced transition rates $B(E2)$ for the upward transitions, and in the values of G , the enhancement of the $B(E2)$. Additional uncertainties in these latter quantities are written last and are discussed in the text. The $B(E2)$ are given in terms of the single-particle values $(\hbar^2/2M)^{1/2} \times 10^{-48} \text{ cm}^2$. The G are found using the single-particle predictions from Table I.

MeV	J	$B(E2)$	Γ_{α} sec ⁻¹	$B(E2)$	G
0.930	1/2	$7.2 \pm 1.1 \times 10^{-48}$	$1.0 \pm 0.24 \times 10^{14}$	$0.467 \pm 0.09 \pm 0.14$	$11.0 \pm 1.7 \pm 3.3$
1.609	3/2	$1.6 \pm 0.35 \times 10^{-48}$	$1.03 \pm 0.16 \pm 0.3$	$4.94 \pm 0.16 \pm 1.4$	
1.813	5/2	$4.0 \pm 1.0 \times 10^{-48}$	$9.23 \pm 1.5 \pm 2.8 \times 10^{13}$	$5.16 \pm 0.9 \pm 0.15$	$5.12 \pm 1.2 \pm 0.9$
1.999	7/2	$9.0 \pm 1.0 \times 10^{-48}$	$2.00 \pm 0.84 \pm 0.67 \times 10^{13}$	$9.516 \pm 0.19 \pm 0.15$	$10.1 \pm 1.7 \pm 3.3$

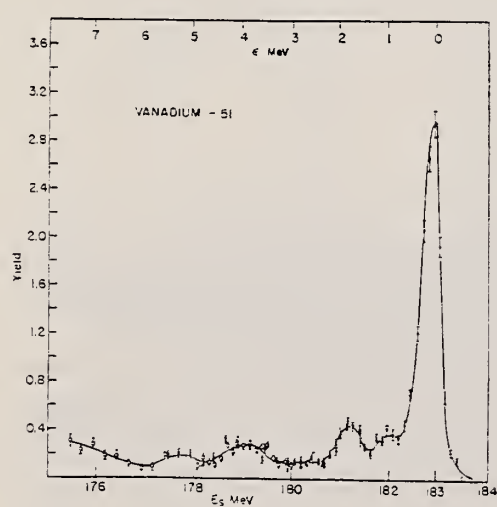


Fig. 2. In this and succeeding figures through Fig. 7 we show raw and corrected spectra of electrons scattered elastically and inelastically from V^{51} and from carbon and polycarbonate. E_s is the scattered electron energy, and E_0 is the nuclear excitation energy after the scattering. Three overlapping runs with the 17-channel detector are indicated by different symbols. The smooth curve is a visual fit to the data. The present figure refers to scattering of 183-MeV electrons from V^{51} at a laboratory angle of 60° .

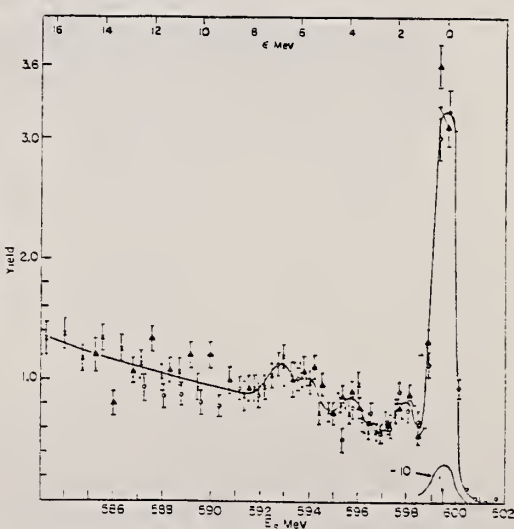


Fig. 4. Scattering of 600-MeV electrons from V^{51} at a laboratory angle of 31° . Cf. caption to Fig. 2.

Method Betatron; solid state detector

Ref. No.	JHH
62 Kr 1	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$V^{51}(\gamma, \alpha)$	Bremss. 21 30			$\int_0^{21} = 2.4 \pm 0.72$ MeV-mb $\int_0^{30} = 6.0 \pm 1.8$ MeV-mb		Data were taken at $\theta_\alpha = 90^\circ$, and isotropy was assumed to get the $\int \sigma dE$ values given here.

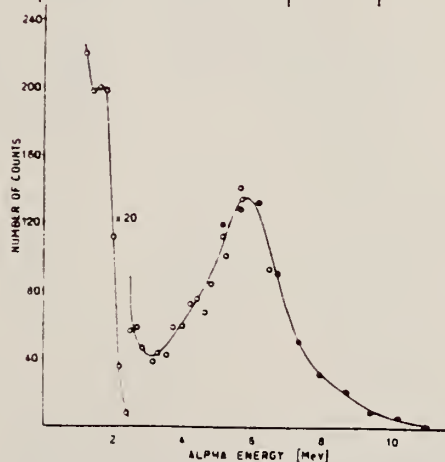


Fig. 2. The α -particle spectrum from $V^{51}(\gamma, \alpha)Sc^{47}$ taken at 90° and 21 MeV end point betatron energy. The lower part was measured with a 300 Ω cm counter (open circles), while the higher part with a 5000 Ω cm counter (black points). The stopping of alphas in the target shifts the peak for about 1.3 MeV. The pulses at the lower part of the spectrum are mostly due to the protons that are effectively cut off at 3.5 MeV α -energy.

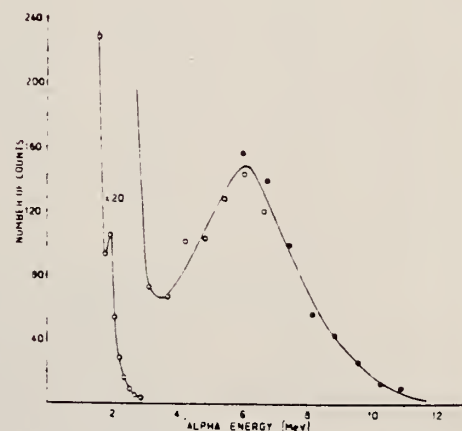


Fig. 3. The α -particle spectrum from $V^{51}(\gamma, \alpha)Sc^{47}$ taken at 90° and 30 MeV end point betatron energy. For explanation see fig. 2.

Ref. Kregar, B. Povh
 Nuclear Phys. 43, 170 (1963)
 Erratum in Nuclear Phys. 47, 528 (1963)

Elem. Sym.	A	Z
V	51	23
Ref. No.		JHH
63 Kr 1		

Method
 Betatron; α yields; solid state detectors; NBS chamber monitor

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
V (γ, α)	Bremss. 21 30					

TABLE I
 Relative yields

Element	21 MeV		30 MeV	
	Number of alphas	Relative yield at 90	Number of alphas	Relative yield at 90
Ni	1209	40	536	13
Cu	1124	13	590	-
Fe	1108	4.5	653	1.7
V	372	1	363	1
Cd	136	0.7		

Method Betatron; proton yield; angular distribution; scintillator;
ion chamber.

Ref. No.
63 Mi 5
NVB

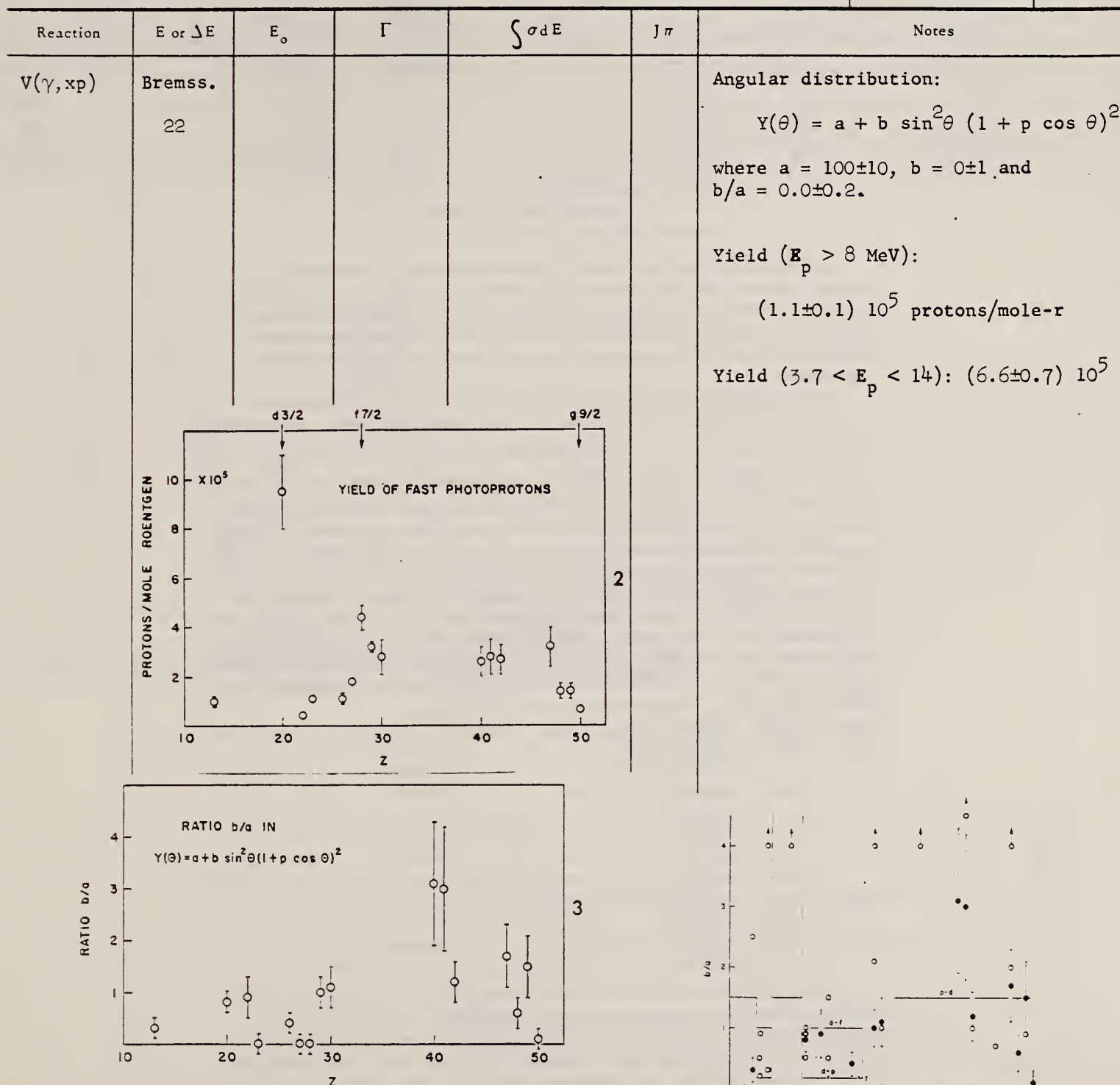


FIG. 2. The yields of fast photoprotons ($E_p > 8$ Mev) obtained from targets of various elements when irradiated with 22-Mev bremsstrahlung. The target thicknesses range from 551 to 572 mg/cm² (about 8 Mev for protons). The errors noted are statistical.

FIG. 3. The anisotropy coefficient b/a for fast photoprotons ($E_p > 8$ Mev) from 16 elements. The errors noted are statistical.

FORM NBS-418
(8-1-63)
USCOMM-DC 18556-P63

FIG. 4. The values of the fast photoproton anisotropy coefficient b/a for the present authors (●) and other workers (○) in the region of the periodic table $10 < Z < 50$. Arrows indicate discontinue points. The references to the results of other workers are given in Table I. The deviations are explained in the text.

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

METHOD

REF. NO.

67 Be 8

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,2N	ABY	20-37	C	25-37	ACT-I		4PI
G,2P	ABY	20-37	C	25-37	ACT-I		4PI
G,A	ABY	10-37	C	25-37	ACT-I		4PI
G,NA	ABY	21-37	C	25-37	ACT-I		4PI
G,3N	ABY	30-37	C	37	ACT-I		4PI

Photonuclear Reactions with Emission of Several Nucleons

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Rensselaer Polytechnic Institute, Troy, N.Y., U.S.A.

Photonuclear reactions were induced on scandium and vanadium by bremsstrahlung at the Rensselaer Electron Linac. The activity of the residual nuclei was measured. The approximate energy dependence of the photonuclear reactions was either estimated by rough application of the photon difference method or calculated. This permitted determination of integrated cross sections by comparison with the activity of a beam monitor with known cross section.

Competing reactions, especially those involving emission of more than one particle, are a sensitive test of evaporation theory. Detailed calculations were therefore performed using various level density formulas. The Fermi gas formula, $\rho \sim e^{2\sqrt{aU}/U^{5/4}}$, (where $a = A/8 \text{ Mev}^{-1}$ and U is the excitation energy minus pairing energy), Weisskopf's formula, $\rho \sim e^{2\sqrt{aU}}$, and the constant temperature formula $\rho \sim e^{(E - E_0)/T}$ were tried. Corrections to the Fermi gas formula for shell effects have been made by Newton¹ and by Gilbert and Cameron². Gilbert and Cameron also proposed a composite formula which joins the Fermi gas expression smoothly to a constant temperature formula below 8 Mev. The calculated integrated cross sections using these formulas were found to differ by as much as several orders of magnitude. The composite formula with Gilbert and Cameron's parameters gave the best overall agreement with our experimental data. The composite formula with optical model inverse cross sections³ and giant resonance data from Fultz, et al.,⁴ are given in the table. Results using the constant temperature, Fermi gas, and Fermi gas formula with shell corrections by Newton have been included in one case. Integrated cross sections are in Mev-mb.

Target	End Point	Results	(γ, n)	($\gamma, 2n$)	($\gamma, 3n$)	($\gamma, 2p$)	(γ, α)	(γ, Cn)
⁴⁵ Sc	48 MeV	Composite	310	78		2.0×10^{-1}		
		Experiment	430 ± 70	68 ± 12		3.0 ± 0.8		
⁵¹ V	37 MeV	Composite		140	1.4	6.3×10^{-1}	3.1	1.6
		Constant T		99	2.0	3.8	1.3	0.37
		Fermi Gas		97	1.3	3.5×10^{-2}	1.0	30
		Newton		101	2.1	3.2×10^{-3}	0.44	8.6
		Experiment		124 ± 35	2.5 ± 0.5	$(2.4 \pm 0.5) \times 10^{-1}$	7.1 ± 1.5	$5.0 \pm 2.$
⁵¹ V	29 MeV	Composite		106		4.2 ± 10^{-2}	2.9	
		Experiment		115 ± 30		$(1.7 \pm 0.3) \times 10^{-2}$	6.8 ± 1.4	
⁵¹ V	25 MeV	Composite		60		3.0 ± 10^{-4}	2.4	
		Experiment		62 ± 12		$(2.6 \pm 0.3) \times 10^{-4}$	4.9 ± 1.2	

When the parameters of Newton were used in a composite level density formula agreement improved but remained significantly poorer than obtained with Gilbert and Cameron's parameters. The large disparity found in the ⁴⁵Sc($\gamma, 2p$) result would be eliminated by a 15 percent increase in the level density parameter of ⁴⁴Ca which has a closed proton shell. Our work indicates that this type of experiment can be of significant value in the study of nuclear level densities.

- References: 1. Newton, T. D. Can. J. Phys. 34, 804 (1956).
2. Gilbert, A. and Cameron, A. G. W. Can. J. Phys. 43, 1449 (1965).
3. Mäldner, H. and Lindner, A. Z. Physik 180, 362 (1964).
4. Fultz, S. C., Bramblett, R. L., Caldwell, J. T., Hansen, N. E., and Jupiter, C. P. Phys. Rev. 128, 2345 (1962).

ELEM. SYM.	A	Z
V	51	23
METHOD		REF. NO.
		68 Ga 1
		egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$G,XN	SPC	THR-85	C	85	CCH	1-15	135

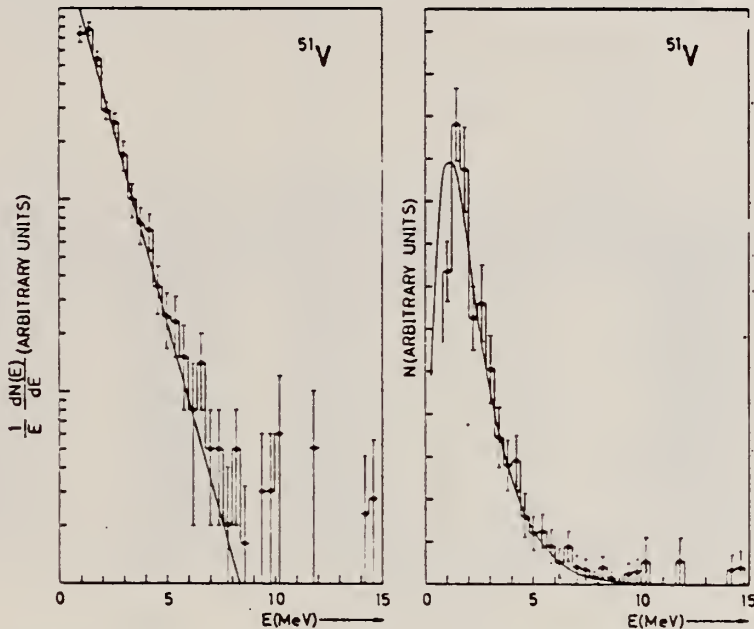


Fig. 2. Energy spectrum of photoneutrons from ^{51}V (at the right) and semi-logarithmic plot of the spectrum after dividing by the neutron energy (at the left). The full line is the typical evaporation spectrum normalized as described in the text.

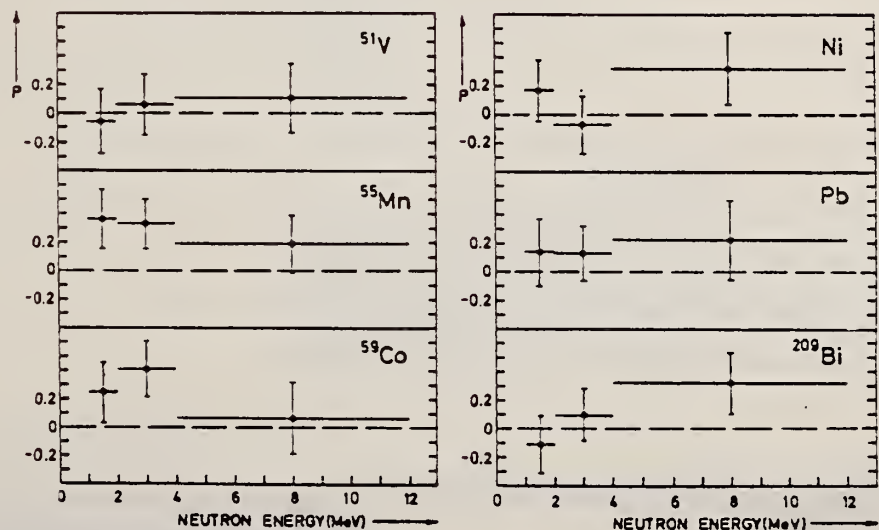


Fig. 7. Polarization of photoneutrons from ^{51}V , ^{55}Mn , ^{59}Co , natural Ni, natural Pb and ^{209}Bi .

REF.

ELEM. SYM.

A

Z

J. W. Jury, J. S. Hewitt, and K. G. McNeill
 Can. J. Phys. 46, 1823 (1968)

V

51

23

METHOD

REF. NO.

68 Ju 1

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G ₂ N	NOX	THR-32	C	32	THR	5-	DST

$$W(\theta) = a_0 + a_1 P_1 + a_2 P_2$$

TABLE I

Target element	Z	Energy	a_0^*	a_1/a_0	a_2/a_0
Vanadium	23	32	640 ± 50	0.11 ± 0.10	-0.09 ± 0.11
Chromium	24	22	365 ± 39	0.02 ± 0.08	0.00 ± 0.10
Manganese	25	22	450 ± 33	0.07 ± 0.05	-0.11 ± 0.06
Bromine	35	27	874 ± 54	0.05 ± 0.06	-0.15 ± 0.08
Molybdenum	42	22	610 ± 60	0.09 ± 0.05	-0.35 ± 0.06
Ruthenium	44	27	1100 ± 25	0.12 ± 0.02	-0.29 ± 0.03
Rhodium	45	27	1270 ± 47	0.06 ± 0.03	-0.14 ± 0.03
Palladium	46	27	1350 ± 29	0.26 ± 0.02	-0.12 ± 0.02
Antimony	51	27	2140 ± 62	0.04 ± 0.08	-0.25 ± 0.11
Lanthanum	57	27	1940 ± 70	0.12 ± 0.10	-0.52 ± 0.14
Praseodymium	59	30	1800 ± 58	0.20 ± 0.08	-0.40 ± 0.09
Platinum	78	27	2600 ± 52	0.17 ± 0.02	-0.15 ± 0.03
Lead	82	22	2274 ± 59	0.08 ± 0.08	-0.46 ± 0.09

*The yield per mole per 100 r was normalized to a yield of 2274 for the lead sample at the same energy.

METHOD					REF. NO.		egf
					68 Me 4		
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,A	ABX	THR-300	C	20-300	ACT-I		4PI
G,A3N	ABX	THR-300	C	20-300	ACT-I		4PI

TABLE 1

Summary of integrated cross sections $\int_0^{E_{max}} \sigma dE(\text{MeV} \cdot \text{mb})$ for the reactions studied

TABLE 1

Summary of integrated cross sections $\int_0^{E_{max}} \sigma dE$ (MeV · mb) for the reactions studied

Reaction/ E_{max} (MeV)	65	105	145	215	295
$^{16}\text{O}(\gamma, 2n)^{14}\text{O}$	0.42 ± 0.02	0.57 ± 0.04	0.56 ± 0.05	0.63 ± 0.09	1.29 ± 0.16
$^{19}\text{F}(\gamma, 2pn)^{14}\text{N}$	3.7 ± 0.2	5.0 ± 0.3	6.1 ± 0.5	8.4 ± 1.0	13.6 ± 1.5
$^{27}\text{Al}(\gamma, 2pn)^{24}\text{Na}$	8.3 ± 0.3	13.3 ± 0.7	17.1 ± 1.2	24.1 ± 2.3	$31.2 \pm 3.3^a)$
$^{51}\text{V}(\gamma, \alpha)^{47}\text{Sc}$	12.3 ± 1.7	20.2 ± 3.5	32.5 ± 2.6	68.4 ± 3.8	112 ± 14
$^{51}\text{V}(\gamma, \alpha 3n)^{44}\text{Sc}$	0.7 ± 0.2	6.0 ± 0.9	12.2 ± 1.3	34.1 ± 4.1	91 ± 11

^{a)} $E_{max} = 275$ MeV.

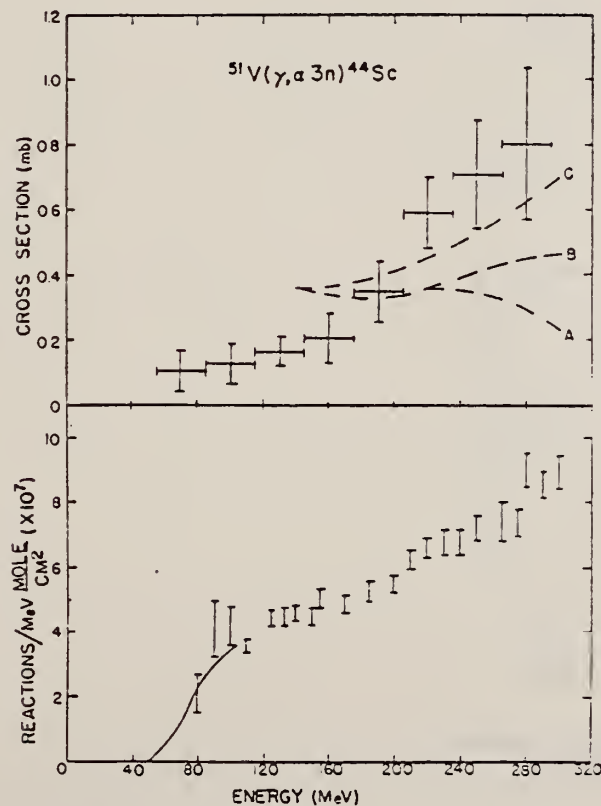


Fig. 5. Yields and cross sections for the $^{51}\text{V}(\gamma, \alpha 3n)^{44}\text{Sc}$ reaction. The solid line shows the assumed extrapolated yield curve behavior near the reaction threshold. The dashed lines have the same significance as in fig. 4.

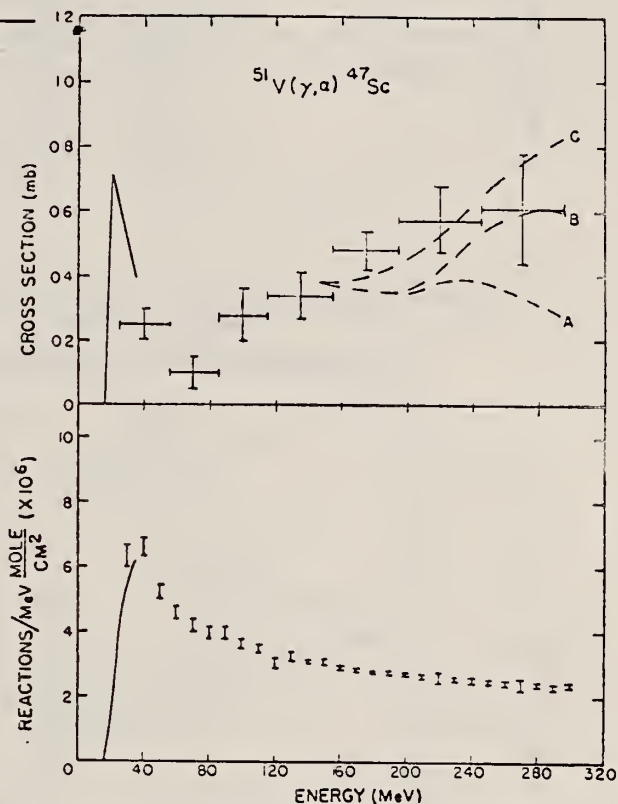


Fig. 4. Yields and cross sections for the $^{51}\text{V}(\gamma, \alpha)^{47}\text{Sc}$ reaction. The solid lines show the normalised low-energy yield and cross section results obtained by Carver ⁸⁾. The dashed line labelled A gives the expected cross sections for quasi-deuteron processes. Dashed line B gives the sum of the cross sections for quasi-deuteron and pion emission processes, and dashed line C gives the cross section sum for all three mechanisms considered (quasi-deuteron, pion emission and pion re-absorption).

REF.	G. Nydahl and B. Forkman Nucl. Phys. <u>B7</u> , 97 (1968)	ELEM. SYM.	A	Z
		V	51	23
METHOD		REF. NO.	68 Ny 1	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
* G,PI+	ABX	140-700	C	140-700	ACT-I		4PI
** G,PI2N	ABX	140-700	C	140-700	ACT-I		4PI

* TI-51 ACT
** CR-49 ACT

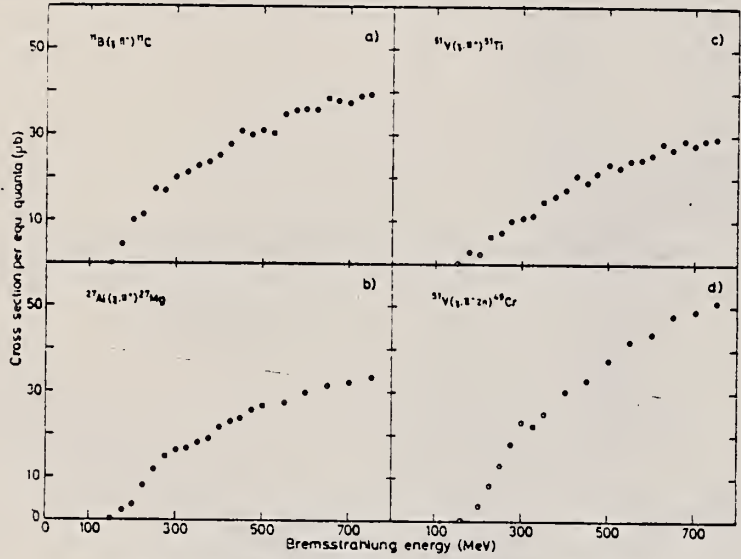


Fig. 3. Absolute yields for the measured reactions.

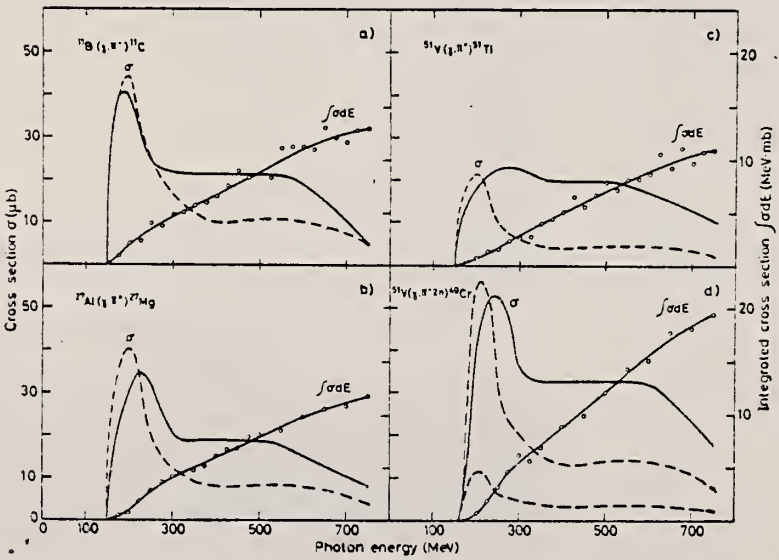


Fig. 4. Experimentally determined true and integrated cross sections. Theoretical calculations of the cross sections are marked with dashed lines.

REACTION		RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
				TYPE	RANGE	TYPE	RANGE	
G.A		ABY	THR-20	C	20	ACT-I		4PI

TABLE 1. SUMMARY OF DATA ON (γ, α) REACTIONS WITH 20 MeV BREMSSTRAHLUNG

Nuclide		E_{th} (-Q, MeV)	Observed gamma-ray			Results obtained	
Parent (Natural abundance, %)	Product (Half-life)		Energy (MeV)	Branching ratio (%)	Type of multipole transition	$\mu\text{Ci/mg}^a$	Yield ($\text{mol}^{-1} \cdot \text{R}^{-1}$)
^{51}V (99.75)	^{47}Sc (3.4 d)	10.27	0.160	100	$M1+E2$	1.99×10^{-3}	2.8×10^3
^{63}Cu (30.9)	^{51}Co (99 min)	6.75	0.068	99	$M1+E2$	7.23×10^{-3}	9.7×10^3
^{71}Ga (39.6)	^{67}Cu (61 hr)	5.15	0.184	41	$M1$	2.70×10^{-3}	9.6×10^3
^{72}Ge (7.67)	^{68}Zn (14 hr)	5.89	0.435	100	$M4$	1.11×10^{-3}	5.0×10^3
^{81}Br (49.48)	^{77}As (39 hr)	6.46	0.246	2.81	$M1+E2$	1.97×10^{-4}	4.3×10^2
^{109}Ag (48.65)	^{105}Rh (36 hr)	3.28	0.319+0.306	24.8	$M1+E2$	8.29×10^{-4}	3.7×10^1
^{115}In (95.77)	^{111}Ag (7.6 d)	3.78	0.340	6	$M1+E2$	5.70×10^{-5}	4.3×10^1

a) The value corrected at the end of 1 hr irradiation ($9.4 \times 10^6 \text{ R/min}$).

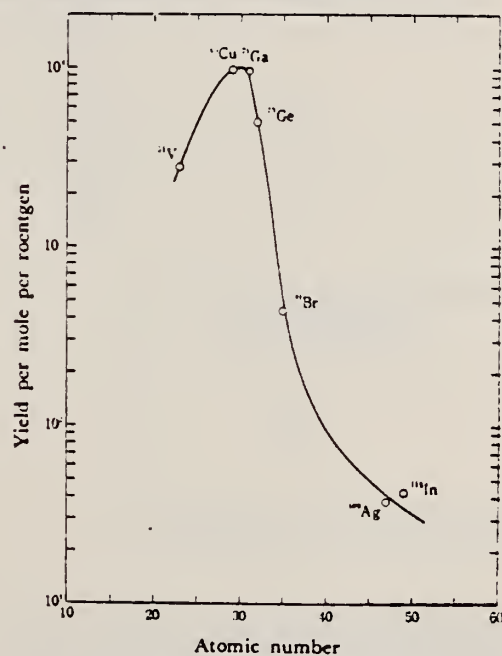


Fig. 1. The yield curve for (γ, α) reaction with 20 MeV bremsstrahlung.

METHOD					REF. NO.		
					69 Ab 2		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XP	SPC	8-27	C	27	SCD-D	3-15	90
		(26.6)		(26.6)			

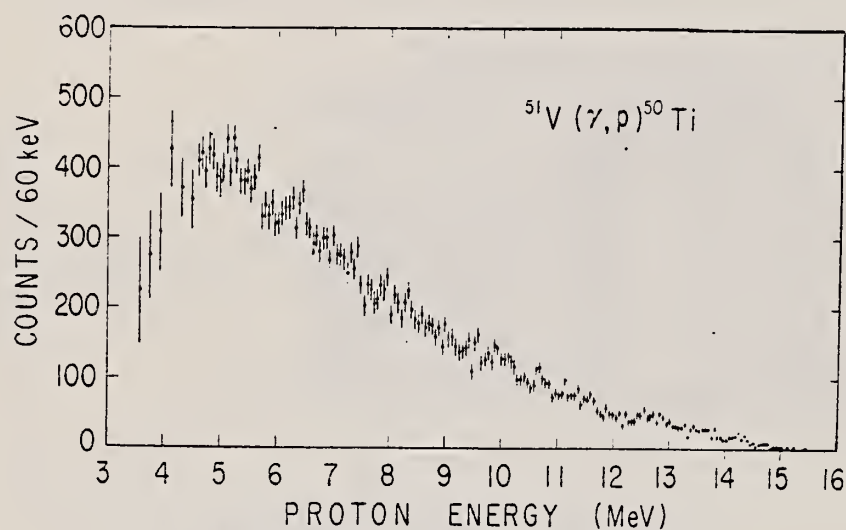


Fig. 1. $^{51}\text{V}(\gamma, p)$ spectrum at 90° , by 26.6 MeV bremsstrahlung.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	SPC	12-85	C	85	CCH-D		135

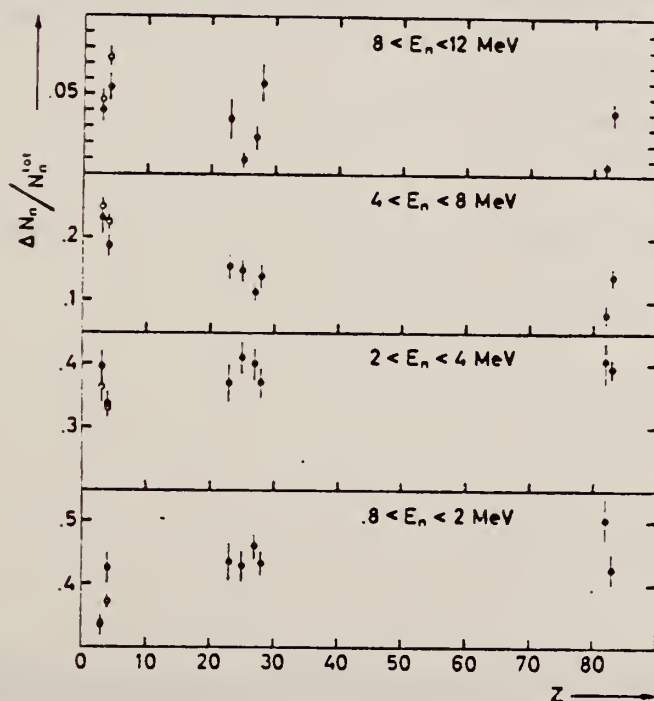


Fig. 1. - Percentage of the photoneutrons emitted at 135° , in the respective energy interval as a function of Z , by a γ -ray bremsstrahlung beam with $E_{\gamma \max} = 85$ MeV. The open circles represent the values obtained at 60° for ${}^7\text{Li}$ and ${}^9\text{Be}$.

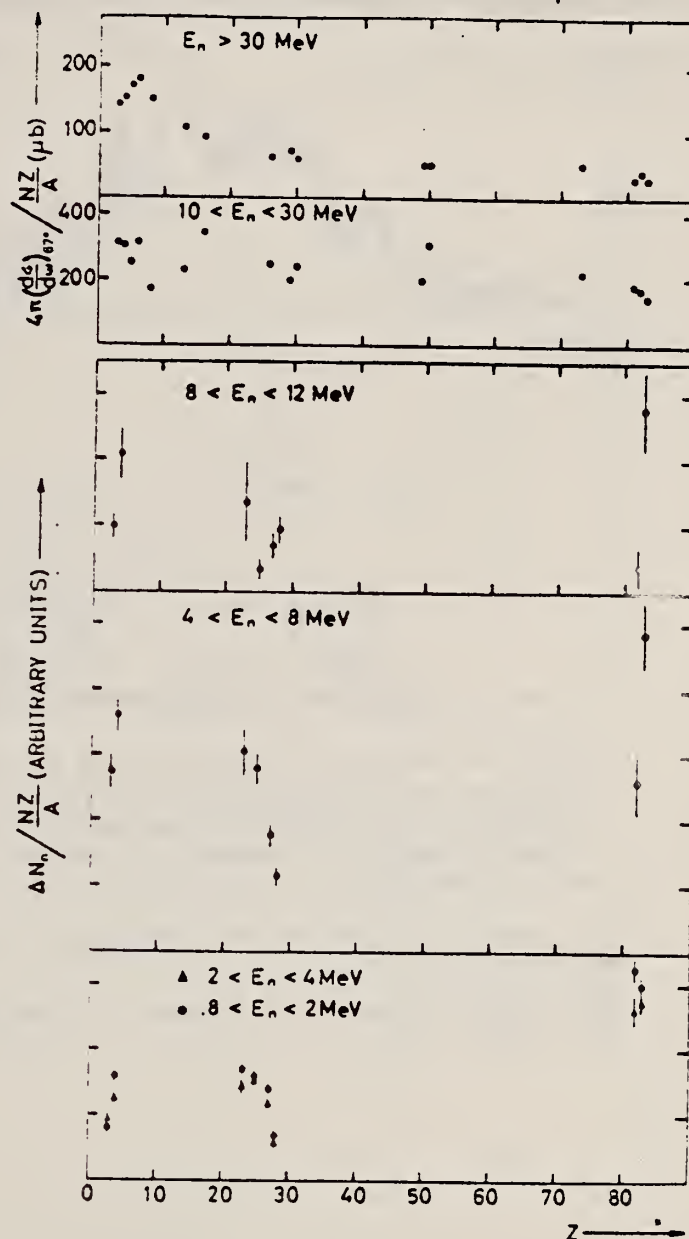


Fig. 2. - Number of photoneutrons emitted at 135° , normalized to the sum rule factor NZ/A , as a function of Z . In the upper part is reported the effective cross section divided by NZ/A for photoproduction of fast neutrons by 55-85 MeV bremsstrahlung photons as deduced by Kaushal *et al.* [1].

¹N.N. Kaushal *et al.*, Phys. Rev. 175, 1330 (1968).

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69 Go 3

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REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	11-30	C	11-30	BF3-I		4PI

448

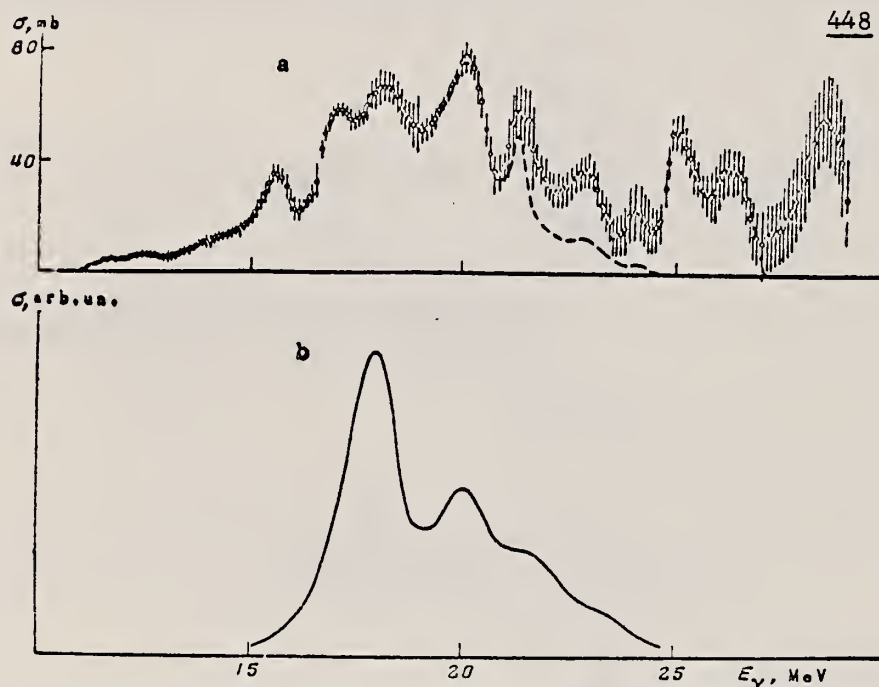


Fig.1. a - The $(\gamma,n) + (\gamma,2n)$ cross section for ^{51}V ; the broken curve represents $\sigma(\gamma,n)$ near the $(\gamma,2n)$ threshold, as deduced from our results via the statistical theory⁵; b - theoretical absorption cross-section from Ref. 6.

⁵J.M. Blatt & V.F. Weisskopf, Theoretical Nuclear Physics, New York, 1952.

⁶M.G. Huber, M. Danos, H.J. Weber & W. Greiner, Phys. Rev. 155, 1073 (1967).

(over)

Characteristics of the Photonutron Cross Sections (in MeV-mb)

Nucleus	Integral cross sections*				Center of gravity $\sigma(\gamma n) + \sigma(\gamma, 2n)$, MeV	Refs.	Dipole sum rule $6NZ/A$, MeV-mb
	$\sigma(\gamma n) + 2\sigma(\gamma, 2n)$	$\sigma(\gamma n) + \sigma(\gamma, 2n)$	$\sigma(\gamma n)$	$\sigma(\gamma, 2n)$			
⁵¹ V	820 (30)	600 (30)	380 (30)	220 (30)	21,3	Our work	760
	670 (28)	560 (28)	450 (28)	110 (28)		[9]	
	590 (24)					[10]	
	560 (25)					[11]	
⁵² Cr	950 (30)	740	530 (30)	210 (30)	20,4	Our work	775
	600 (24)	[10]					
⁵⁸ Co	1030 (30)	740 (30)	450 (30)	290 (30)	20,2	Our work	880
	730 (28)	590 (28)	450 (28)	140 (28)		[9]	
	870 (29)					[12]	
	840 (25)					[13]	
	660 (28)					[14]	
	630 (25)					[11]	

*The upper integration limits are given in parentheses.

9. S.C.Fultz, R.L.Bramblett, I.T.Caldwell, N.E.Hansen & C.P.Jupiter, Phys. Rev. 128, 2345 (1962).
10. J.Goldemberg & L.Katz, Canadian J. Phys. 32, 49 (1954).
11. B.Nathans & J.Halpern, Phys. Rev. 93, 437 (1954).
12. E.B.Bazhanov, A.P.Komar & A.V.Kulikov, Zh. Eksperim. i teor. fiz. 46, 1497 (1964). (Trans. Soviet Physics - JETP.)
13. P.A.Flournoy, R.S.Tickle & W.D.Whitehead, Phys. Rev. 120, 1424 (1960).
14. G.Baciu, G.C.Bonazzola, B.Minetti, C.Molino, L.Pasqualini & G.Piragino, Nuclear Phys. 68, 178 (1965).

METHOD

REF. NO.

69 Ok 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,3N	RLY	THR-60	C	30-60	NAI-D		4PI
G,SC46	RLY	THR-60	C	30-60	NAI-D		4PI
G,SC47	RLY	THR-60	C	30-60	NAI-D		4PI
G,SC48	RLY	THR-60	C	30-60	NAI-D		4PI

YLD REL 12C(G,N)

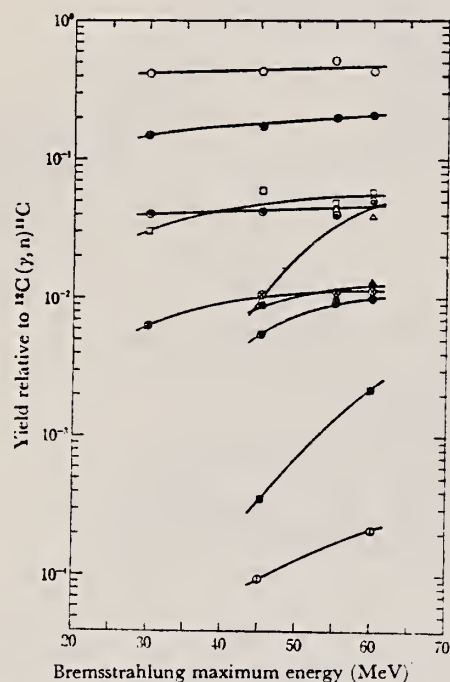


Fig. 6. The yield relative to $^{12}\text{C}(\gamma, n)^{11}\text{C}$ as a function of bremsstrahlung maximum energy.

- : ^{45}Ti from titanium
- : ^{44}Sc from titanium
- ⊙ : ^{46}Sc from titanium
- ⊗ : ^{47}Sc from titanium
- ⊘ : ^{48}Sc from titanium
- △ : ^{48}V from vanadium
- ▲ : ^{46}Sc from vanadium
- : ^{47}Sc from vanadium
- : ^{48}Sc from vanadium
- ⊕ : ^{47}Ca from titanium

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	ABX	12-30	C	32	NAI	12-30	DST

GETS G,G/ TO 2+

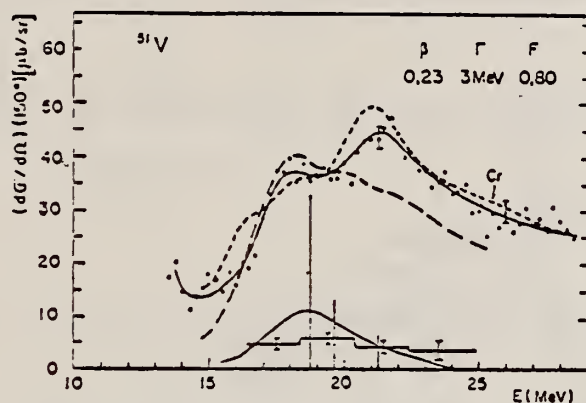


Fig. 5. Differential total scattering cross section at 150° for ⁵¹V. See caption for fig. 4. To compare with ⁵¹V the scattering cross section for Cr is shown.

Fig. 4. Differential total scattering cross section at 150° for natural Ti. The full curve through experimental points is only a guide for the eyes. The vertical bars represent the relative strength of dipole levels calculated by the D.C.M. with parameters of table 1. Theoretical elastic plus inelastic scattering is computed from these levels with a common width Γ (dashed curve). Experimental inelastic scattering (histogram) and theoretical inelastic scattering to the first 2⁺ (full curve) are shown in the lower part of the figure. Open circles give the cross section after background subtraction.

TABLE 4
Integrated inelastic scattering cross section

Nucleus	Limits of integration (in MeV)	Experimental ^{a)} $\int \sigma_i(E) dE$ (MeV · μ b)	2 ⁺	Theoretical ^{a)} 2 ⁺ (MeV · μ b)	Total
Ti(⁴⁸ Ti)	16-24	250 ± 50	425	109	534
⁵¹ V(⁵² Cr)	16.4-24.9	492 ± 50	509	116	579
Cr	16.4-23.4	431 ± 60	509	116	579
⁷³ As(⁷⁶ Se)	14.1-23.6	1254 ± 120	1373	414	1787
Se(⁸⁰ Se)	14.1-24.6	1035 ± 100	1066	353	1419
⁸⁹ Y					364
Cd(¹¹² Cd)	13.6-23.3	3264 ± 240	1894	370	2264
In(¹¹⁴ Cd)	13.6-23.6	2840 ± 220	2173	388	2561
Sn(¹¹⁰ Sn)	14.2-24.2	2363 ± 220			643

^{a)} We assume an angular distribution of the form $1 + \frac{1}{3} \cos^2 \theta$.

G. J. Kumbartzki, Ung Kim and Ch. K. Kwan			ELEM. SYM.	A	Z
Nucl. Phys. <u>A160</u> , 237 (1971)			V	51	23
METHOD			REF. NO.		
			71 Ku 2		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G, SPL	ABY	THR-999	C	800-999	4PI

$$\sigma_q(A,Z) = K \exp [PA - R(A - SZ + TZ^2)^2], \text{ cross section for equivalent quantum.}$$

999 = 2.1 GeV

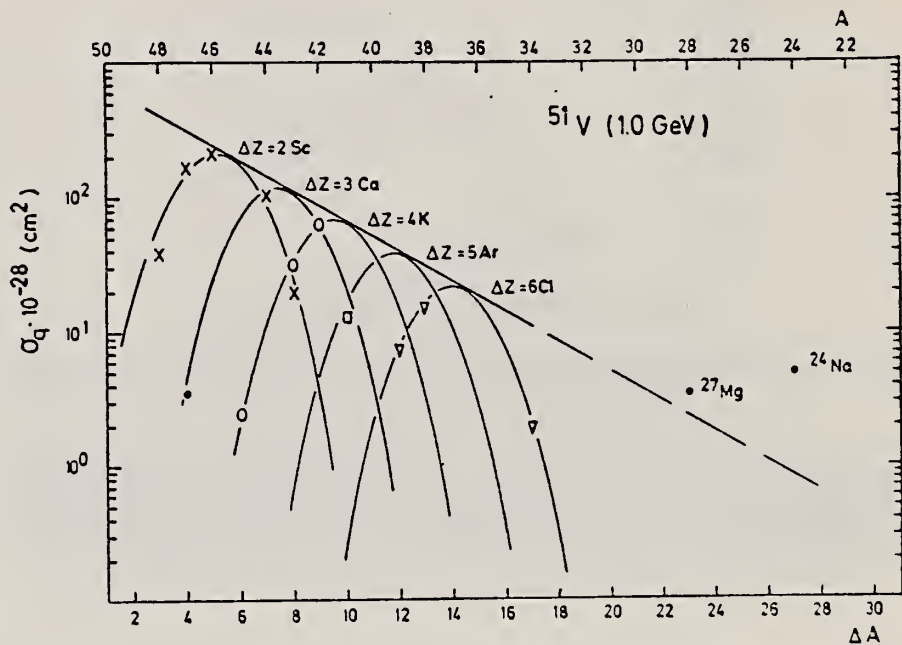


Fig. 3. Photonuclear yields obtained from vanadium after irradiation with 1.0 GeV bremsstrahlung as a function of the number of emitted nucleons.

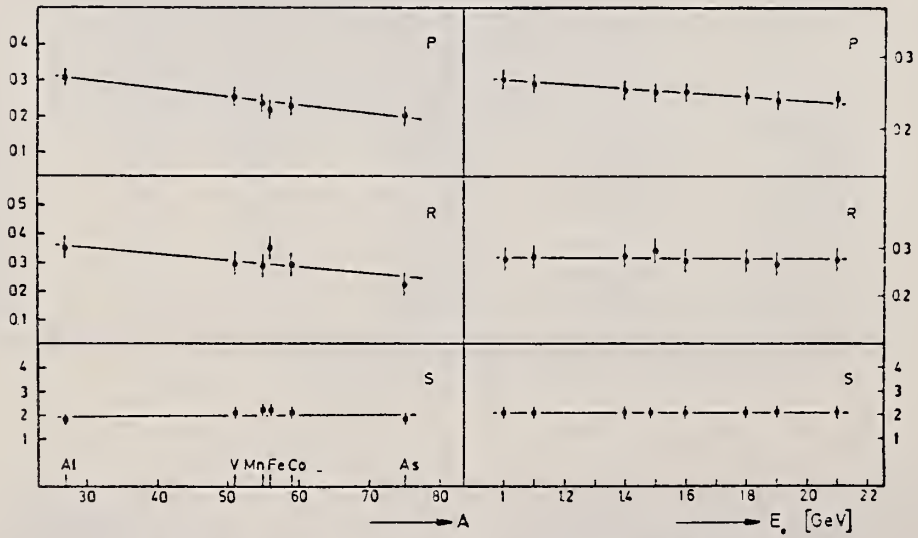


Fig. 6. Behaviour of the parameters *P*, *R* and *S* as functions of *A* and *E*₀.

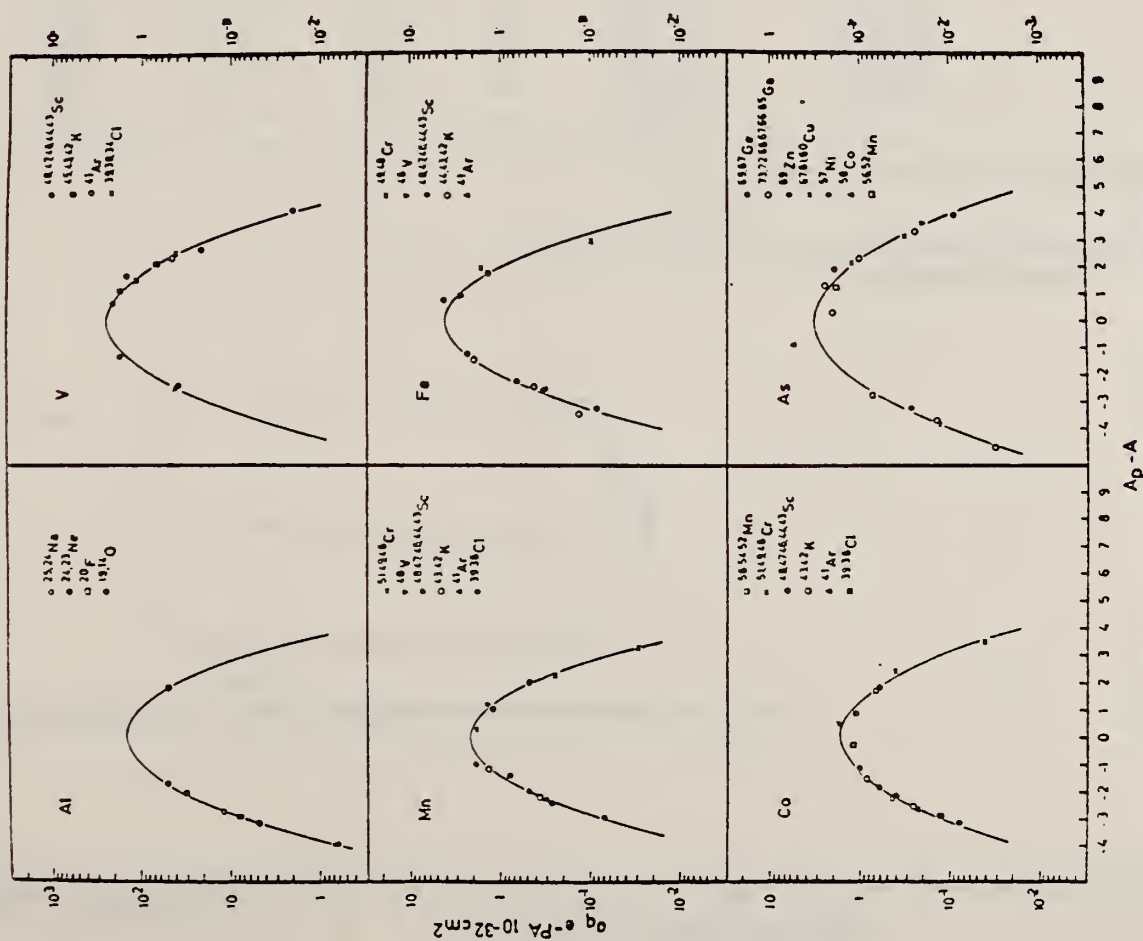


Fig. 4. Yield distributions from various targets with bremsstrahlung of 1.5 GeV.

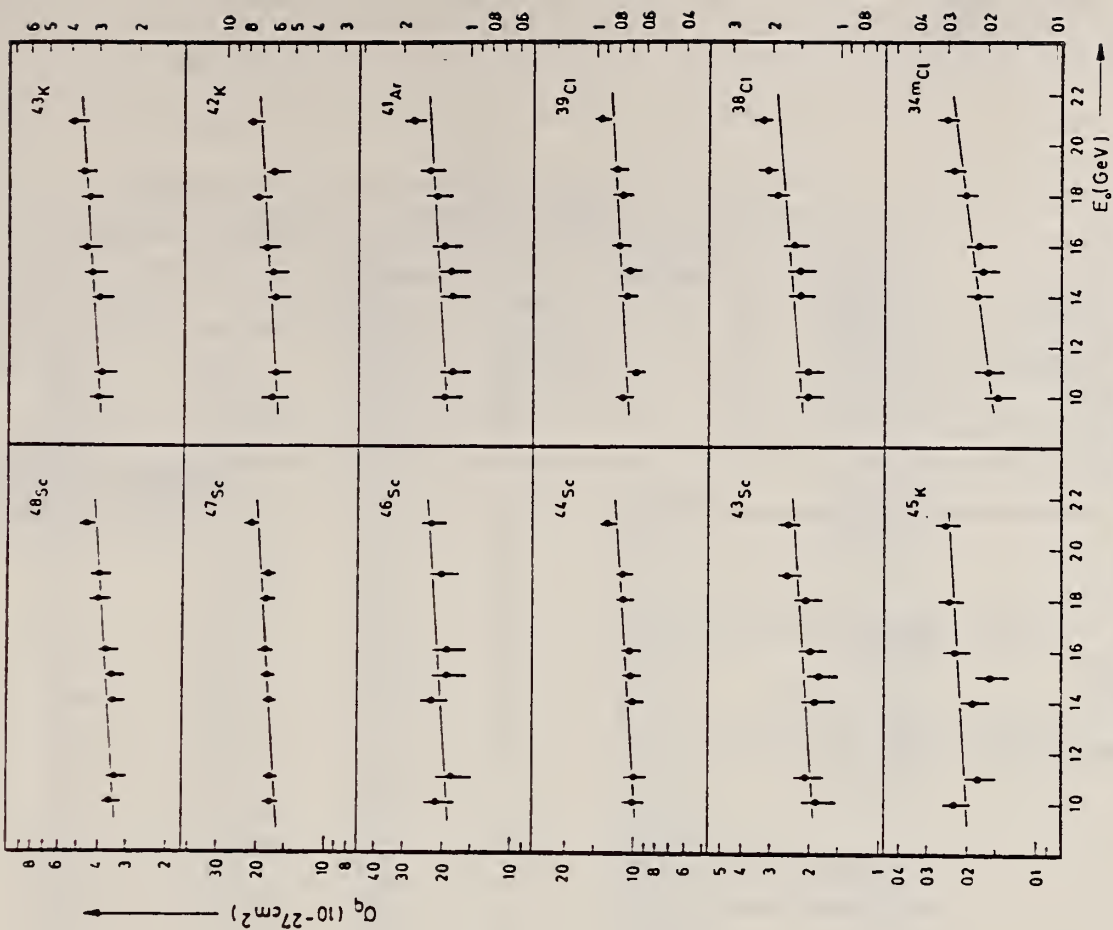


Fig. 5. Yields of spallation products using vanadium targets.

ELEM. SYM.	A	Z
V	51	23
REF. NO.	71 Ku 5	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
* G, SPL	ABY	THR-999	C	999	ACT-I		4PI
** G, PI+	ABY	THR-999	C	200-999	ACT-I		4PI

* 999 = 1.5 GEV
**999 = 2.2 GEV

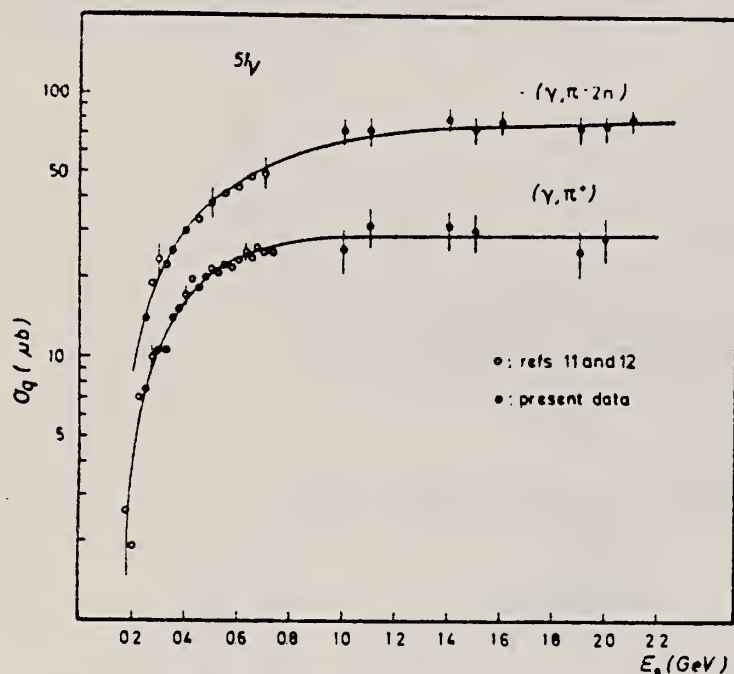


Fig. 2. Yields for the reactions $^{51}\text{V}(\gamma, \pi^+)^{51}\text{Ti}$ and $^{51}\text{V}(\gamma, \pi^-2n)^{49}\text{Cr}$ as a function of the maximum energy of bremsstrahlung.

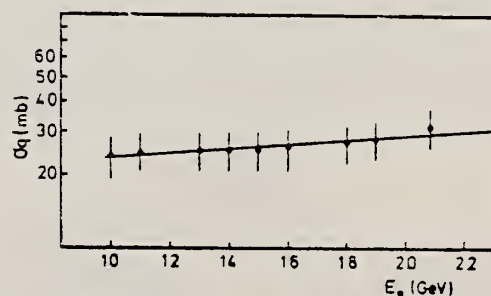


Fig. 4. Total spallation yields of vanadium target as a function of bremsstrahlung energy.

(over)

TABLE I
Decay data and yields of radioactive nucleides in vanadium and iron at 1.5 GeV
bremsstrahlung energy

Nuclide	Half-life	Gamma- energy (keV)	Intensity	$\sigma_a (10^{-28} \text{ cm}^2)$ (vanadium)	$\sigma_a (10^{-28} \text{ cm}^2)$ (iron)
^{55}Fe	8.6 min	380.0	32		12.6 ± 1.6
^{52}Fe	8.2 h	168.1	100		0.40 ± 0.05
^{56}Mn	2.57 h	846.7	100		3.5 ± 0.4
^{54}Mn	312 d	834.8	100		72.0 ± 9.0
^{52}Mn	21 min	1434.4	98		9.1 ± 1.0
^{52}Mn	5.7 d	1434.4	100		7.9 ± 0.9
^{51}Cr	27.8 d	320.1	9		39 ± 4
^{49}Cr	42 min	153.6	13	0.77 ± 0.09	5.9 ± 0.6
^{48}Cr	23 h	307.8	99		0.46 ± 0.6
^{48}V	16 d	983.7	100	10.2 ± 1.3	12.8 ± 1.4
^{52}V	3.8 min	1434.4	100		1.6 ± 0.3
^{51}Ti	5.8 min	320.1	95	0.31 ± 0.07	
^{48}Sc	1.83 d	1038.5	100	3.49 ± 0.43	0.34 ± 0.06
^{47}Sc	3.4 d	159.4	70	18.2 ± 2.7	1.63 ± 0.20
^{46}Sc	83.9 d	1120.0	100	19.4 ± 3.3	4.8 ± 0.7
^{44}Sc	2.44 d	270.8	86	5.2 ± 0.7	3.8 ± 0.4
^{46}Sc	3.92 h	1156.9	100	5.2 ± 0.8	4.1 ± 0.5
^{45}Sc	3.92 h	372.8	22	1.8 ± 0.2	1.9 ± 0.3
^{43}K	22.4 h	617.2	81	3.1 ± 0.4	0.51 ± 0.08
^{42}K	12.4 h	1524.7	18	6.2 ± 0.9	2.4 ± 0.5
^{44}K	22 min	1156.9	61	1.7 ± 0.3	
^{43}K	20 min	175	80	0.20 ± 0.05	
^{41}Ar	1.83 h	1293.0	99	1.24 ± 0.21	0.26 ± 0.04
^{39}Cl	55.5 min	1266.4	50	0.71 ± 0.12	0.16 ± 0.04
^{38}Cl	37.3 min	1642.2	33	1.47 ± 0.21	0.48 ± 0.09
^{36}Cl	32 min	147.2	45	0.21 ± 0.04	
^{28}Al	6.6 min	1273.1	94	0.41 ± 0.09	0.28 ± 0.08
^{28}Al	2.3 min	1778.7	100	0.86 ± 0.15	0.78 ± 0.12
^{28}Mg	21 h	1342.0	70	0.09 ± 0.03	0.03 ± 0.01
^{27}Mg	9.5 min	843.2	70	0.42 ± 0.07	0.18 ± 0.04
^{24}Na	15 h	1368.5	100	0.51 ± 0.08	0.29 ± 0.04
^{24}Ne	3.4 min	472.0	100	0.04 ± 0.01	

REF.	P.K.A. de Witt Huberts, J.E.P. de Bie PICNS-72, 421 (1972) Sendai				ELEM. SYM.	A	Z
					V	51	23
METHOD					REF. NO.		
					72 De 9		hvm
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,E/	FMF	1, 2	D	25- 85	MAG-D		DST

1=1.61; 2=2.41 MEV

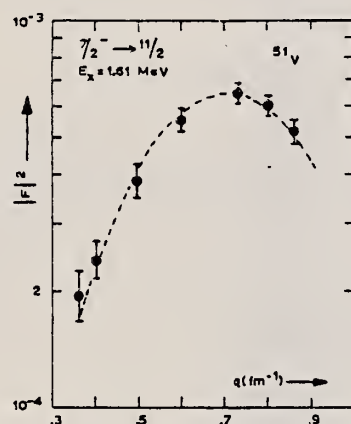


Fig. 8. Experimental form factor for the 1.61 MeV transition in ^{51}V . The dashed curve is the best fit result obtained with a $(1f_{7/2} \rightarrow 1f_{7/2})$ transition density in a harmonic oscillator basis.

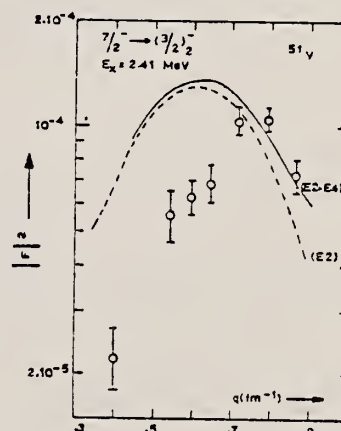


Fig. 9. Experimental form factor for the 2.41 MeV transition in ^{51}V . The two curves shown are the DWBA predictions for E2 and (E2+E4) strength obtained with a $(1f_{7/2} \rightarrow 2p_{3/2})$ transition density in a harmonic oscillator basis.

REF.

D. Hiramatsu, T. Kamae, H. Muramatsu, K. Nakamura, N. Izutsu,
and Y. Watase
PICNS-72, p.429 Sendai (see 73H15)

ELEM. SYM.

A

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51

23

METHOD

REF. NO.

72 H1 8

hvm

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,E/P	NOX	0* 60	D	700	MAG-D		DST

*SEP ENERGY RANGE

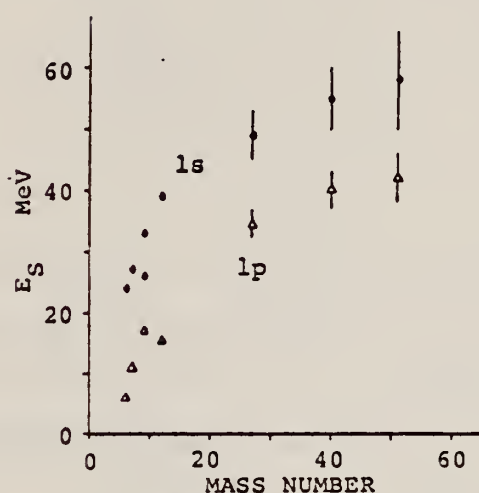


Fig. 6. The separation energy of 1s and 1p states as a function of the mass number.

METHOD

REF. NO.

72 Ke 4

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,A	RLY	10-32	C	32	SCD-D		DST

TABLE 3. Observed angular distribution parameters for 32 MeV electron energy

Element	A_0	A_1, A_1	A_2, A_1
Ti	7.05 ± 0.15	0.073 ± 0.052	-0.286 ± 0.073
V	2.58 ± 0.06	0.037 ± 0.042	-0.126 ± 0.069
Fe	10.22 ± 0.30	0.006 ± 0.043	-0.333 ± 0.072
Co	6.80 ± 0.20	0.022 ± 0.048	-0.016 ± 0.077
Ni	15.95 ± 0.49	0.051 ± 0.048	-0.213 ± 0.074
Cu	8.37 ± 0.28	0.076 ± 0.056	-0.035 ± 0.081
Zn	17.87 ± 0.61	0.004 ± 0.045	-0.270 ± 0.073
Ag	0.39 ± 0.01	0.115 ± 0.049	$+0.093 \pm 0.074$

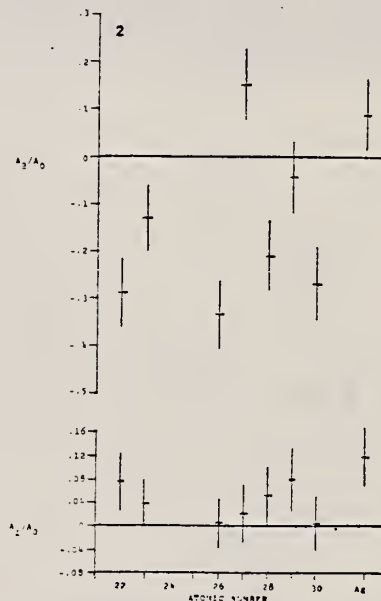


FIG. 2. Angular distributions for 32 MeV electron energy.

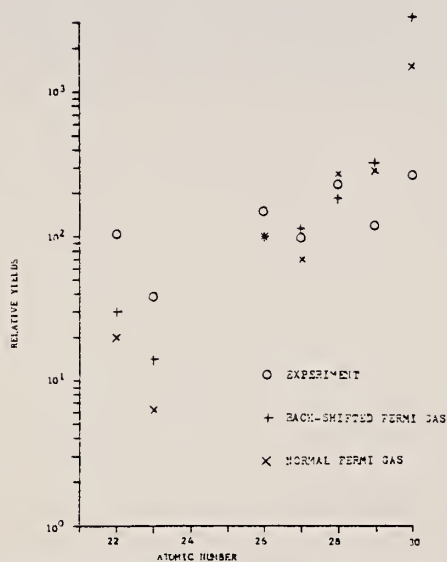


FIG. 13. Experimental and theoretical relative photo-alpha yields for 32 MeV electron beam energy.

REF.

G.A. Peterson, K. Hosoyama, M. Nagao, A. Nakada, Y. Torizuka
 PIQNS-72, 399 (1972) Sendai
 (See 73 Pe 1)

ELEM. SYM.	A	Z
V	51	23
REF. NO.		hvm
72 Pe 3		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	0- 4	D	183,250	MAG-D		DST

7 LEVELS

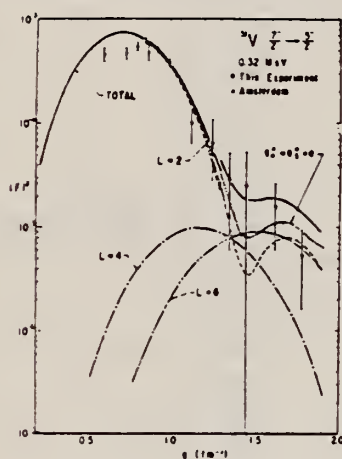


Fig. 1. Form factors for the 0.32 MeV($5/2^-$) state.

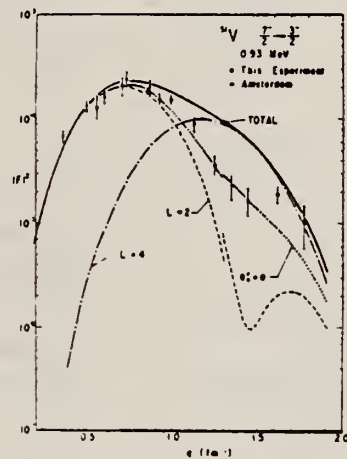


Fig. 2. Form factors for the 0.93 MeV($3/2^-$)₁ state

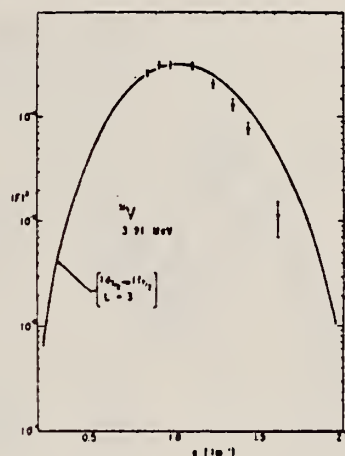


Fig. 7. Form factors for the 3.91 MeV state.

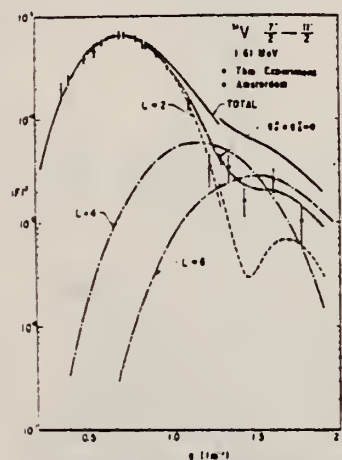


Fig. 3. Form factors for the 1.61 MeV($11/2^-$) state.

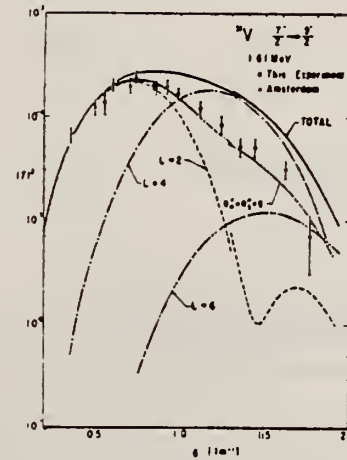


Fig. 4. Form factors for the 1.81 MeV($9/2^-$) state.

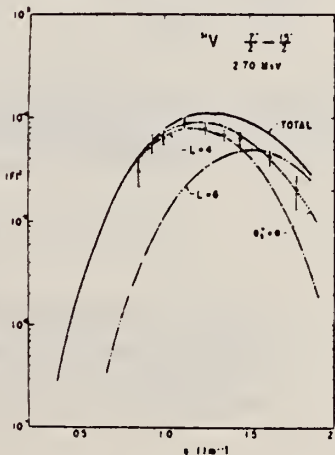


Fig. 5. Form factors for the 2.70 MeV($15/2^-$) state.

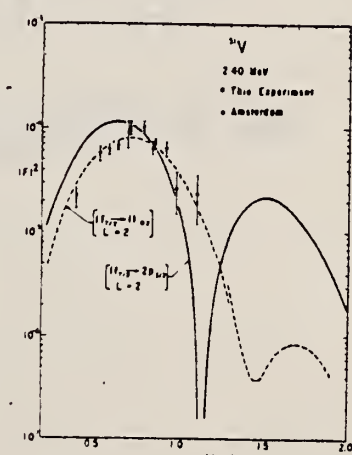


Fig. 6. Form factors for the 2.40 MeV($3/2^-$)₂ state.

R.F. Barrett, J.R. Birkelund, B.J. Thomas, K.S. Lam, and H.H. Thies Nucl. Phys. <u>A210</u> , 355 (1973)			V	51	23
METHOD			REF. NO.		
			73 Ba 20		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,N	NOX	THR- 27	C	10- 27	4PI

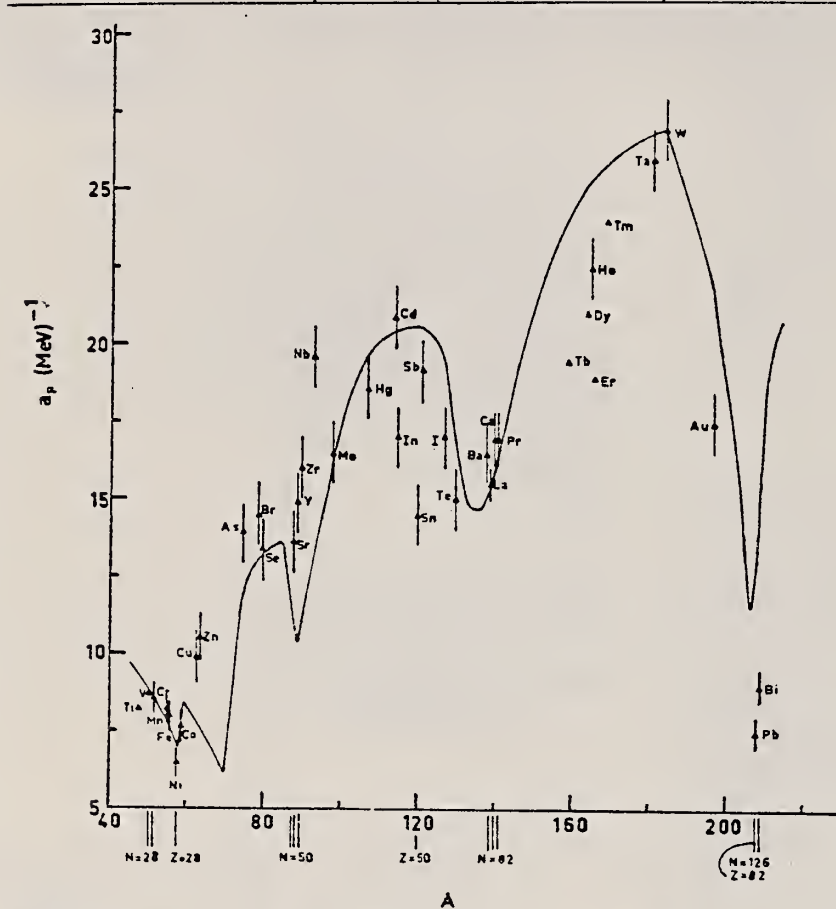


Fig. 12. Experimental values of the level density parameter a_p (Fermi gas formula plus pairing correction) versus atomic number A . The continuous curve is a least-squares fit to the data of a theoretical calculation from Newton ¹⁵.

- 1 H. Baba and S. Baba, Japan Atomic Energy Research Institute report JAERI-1183 (1969).
- 2 H. Baba, Nucl. Phys. A159, 625 (1970).
- 15 T.D. Newton, Can. J. Phys. 34, 804 (1956).

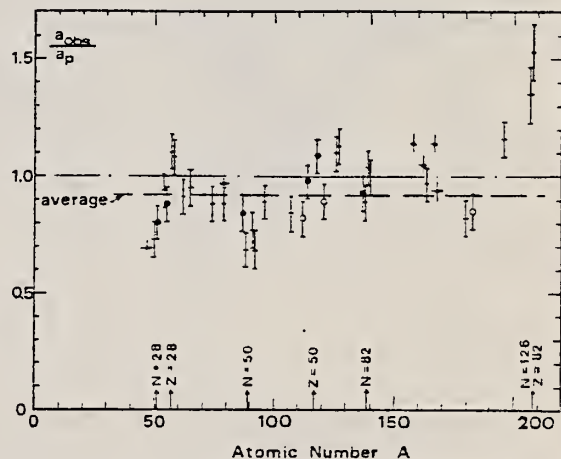


Fig. 15. Ratio a_{obs}/a_p versus atomic number A . Here a_{obs} is the level density parameter taken from the neutron resonance work of refs. ^{1,2}, and a_p is the level density parameter derived from the present (γ, n) work. Filled circles represent points where nuclei in the neutron resonance and in the (γ, n) experiment were the same. Open circles represent points where the respective nuclei were approximately matched. Triangles represent points which are based on measurement of neutron mean energies at two bremsstrahlung energies only.

(over)

TABLE 3
Comparison of experimental and theoretical data on nuclear level densities with Fermi gas formulae, and comparison of nuclear level density parameters from (γ , n) and n-resonance absorption experiments

Target	N (residual nucleus) ^{a)}	Goodness of fit ^{b)}		$\bar{E}_n(24)$ (MeV) ^{c)}	T (MeV) ^{d)}	a_p (MeV ⁻¹) ^{e)}	a_{obs} (MeV ⁻¹) ^{f)}	a_{obs}/a_p
Ti ^{g)}	23	8%		1.93		8.1- ⁴⁷ Ti	6.41- ⁴⁷ Ti	0.79
	24	8%						
	25	73%						
	26	5%						
	27	5%						
V ^{g)}	27	100%		1.96		8.7- ⁵⁰ V	6.35- ⁵¹ V	0.73
Cr	25	4%	P	1.89		8.6- ⁵¹ Cr	6.9 - ⁵¹ Cr	<u>0.80</u>
	27	84%						
	28	10%						
	29	2%						
Mn	29	100%	V.P.	2.1		8.2- ⁵⁴ Mn	7.82- ⁵⁶ Mn	0.94
Fe	27	6%	F	1.96		8.0- ⁵⁵ Fe	7.06- ⁵⁵ Fe	<u>0.88</u>
	29	92%						
	30	2%						
Co	31	100%	P	2.12		7.7- ⁵⁸ Co	8.35- ⁶⁰ Co	1.08
Ni (Z = 28)	29	68%	V.P.	2.04	1.4	6.5- ^{57,7} Ni	7.19- ⁵⁹ Ni	1.10
	31	26%	P					
	32	1%						
	33	4%						
	35	1%						
Cu	33	69%	V.P.	1.78	1.0	9.8- ⁶² Cu	8.90- ⁶⁴ Cu	0.91
	35	31%	P					
Zn	33	49%	F	1.61		10.5- ^{64,4} Zn	10.0- ⁶⁵ Zn	0.95
	35	28%	F					
	36	4%						
	37	19%						
As	41	100%	V.P.	1.44		14.5- ⁷⁴ As	12.81- ⁷⁶ As	0.88
Se ^{g)}	41	9%		1.39		13.3- ⁷⁸ Se	12.8 - ⁷⁸ Se	<u>0.97</u>
	42	8%						
	43	24%						
	45	50%						
	47	9%						
Br	43	45%	V.P.	1.41		14.5- ⁷⁹ Br	12.69- ⁸⁰ Br	0.88
	45	49%	V.P.					
Sr	47	10%	F	1.31		13.6- ⁸⁷ Sr	11.4 - ⁸⁷ Sr	<u>0.84</u>
	48	7%	G					
	49	83%						

^{a)} Neutron numbers and abundances of respective residual nuclei in (γ , n) experiments.

^{b)} These give an assessment of the goodness of fit of a calculated \bar{E}_n versus E_0 curve to the observed data, using the Fermi gas level density formula both without and with pairing corrections.

^{c)} Bremsstrahlung photoneutron mean energies \bar{E}_n for peak bremsstrahlung energy $E_0 = 24$ MeV.

^{d)} Nuclear temperature from fit with constant-temperature formula.

^{e)} Level density parameter a_p derived from the present (γ , n) experiment, using a Fermi gas formula plus pairing correction, and corresponding residual nucleus (the atomic weight shown is the weighted average of atomic weights of the respective isotopes present).

^{f)} As column 7, but using data on n-resonance absorption from refs. ^{1,2}).

^{g)} Measurements of $\bar{E}_n(E_0)$ for these nuclei were made only for $E_0 = 21, 23$ and 24 MeV.

REF.

R. Bergere, H. Beil, P. Carlos, A. Lepretre, A. Veyssiere
PICNS-73, Vol.I, p.525 Asilomar

ELEM. SYM.

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METHOD

REF. NO.

73 Be 10

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	13- 28	D	13- 28	BF3-I		4PI
G,2N	ABX	20- 28	D	20- 28	BF3-I		4PI

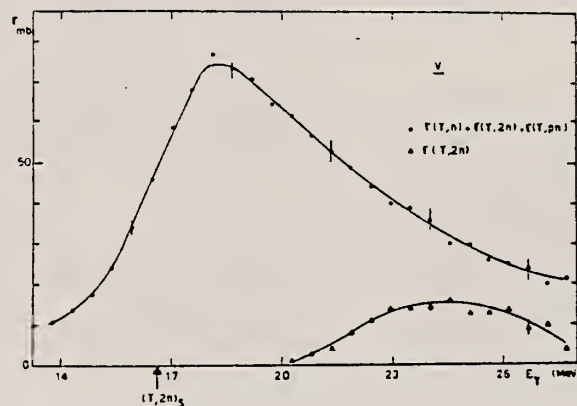


Fig. 12 Partial photoneutron $\sigma(\gamma,n) + \sigma(\gamma,pn)$
and $\sigma(\gamma,2n)$ cross sections of ^{51}V .

REF.

A. Järund, B. Friberg, and B. Forkman
Z. Physik 262, 15 (1973)

ELEM. SYM.

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METHOD

REF. NO.

73 Ja 3

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,NA24	ABY	THR-999	C	100-999	ACT-I		4PI

999=1 GEV

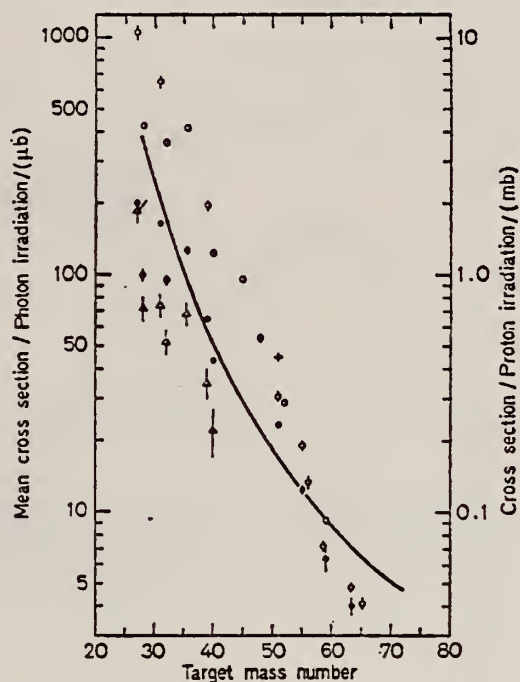


Fig. 7. Mean cross sections for ^{24}Na production as a function of target mass number. Present work filled circles. Noga *et al.* [3] open triangles, Kumbartzki *et al.* [13] cross and Korteling *et al.* [1] 400 MeV protons open circles. The solid line gives the mean cross sections calculated by Jonsson *et al.* [17]

¹Korteling, R.G. *et al.*, J. Inorg. Nucl. Chem. 29, 2863 (1967).

³Noga, V.I. *et al.*, Sov. J. Nucl. Phys. 9, 637 (1969).

¹³Kumbartzki, G. *et al.*, Nucl. Phys. A176, 23 (1971).

¹⁷Jonsson, G.G. *et al.*, LUNP7212, Oct. 1972, to be published in Physica Scripta.

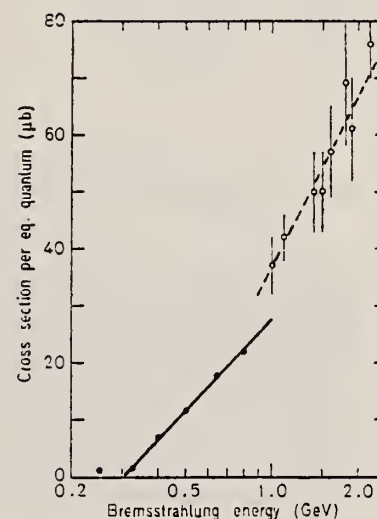


Fig. 5

Fig. 5. The determined yield for the reaction $^{51}\text{V} \rightarrow ^{24}\text{Na}$. Present work filled circles, Kumbartzki *et al.* [13] open circles

METHOD

REF. NO.

Page 1 of 3

73 Pe 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	G- 4	D	183,250	MAG-D		DST

7 LEVELS

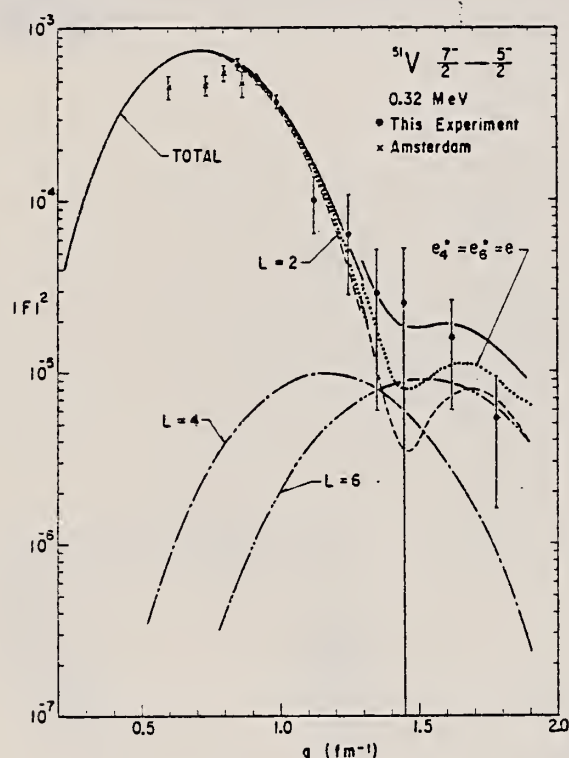


FIG. 6. The square of the form factor for the excitation of the 0.32-MeV level of ^{51}V by inelastic electron scattering versus momentum transfer. The calculated form factors are for a $(1f_{7/2})^3$ configuration of protons in a harmonic-oscillator potential. The curves for the $L=2$, $L=4$, and $L=6$ multipoles and their total were calculated for an effective charge of $1.84e$. The curve labeled $e_4^* = e_6^* = e$ is the sum of the form factors assuming the effective charge is $1.84e$, e , and e for the $L=2$, 4 , and 6 multipoles, respectively.

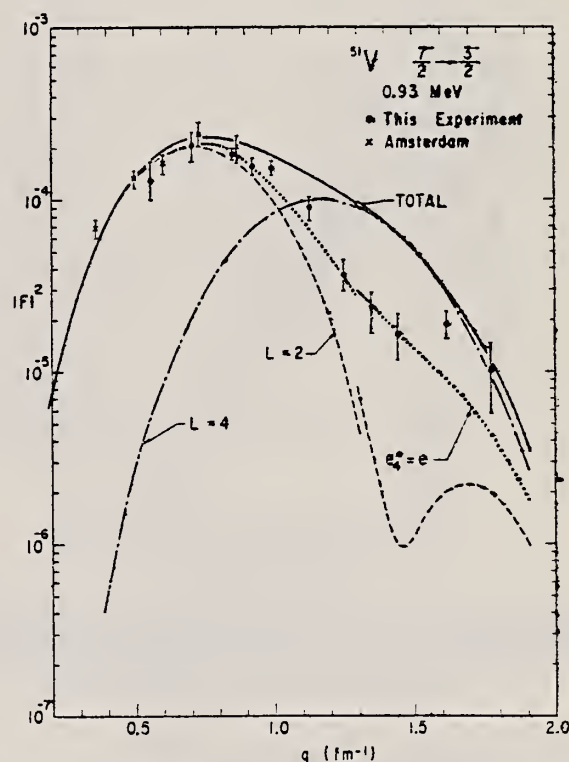


FIG. 7. Form factors for the 0.93-MeV excitation. See the caption to Fig. 6. The total curve was calculated assuming an effective charge of $2.01e$.

(over)

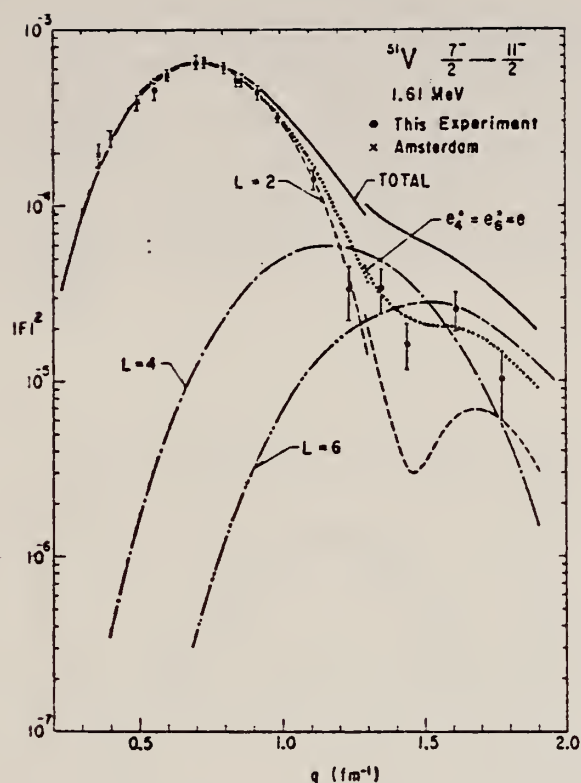


FIG. 8. Form factors for the 1.61-MeV excitation. See the caption to Fig. 6. The total curve was calculated for an effective charge of $1.79e$.

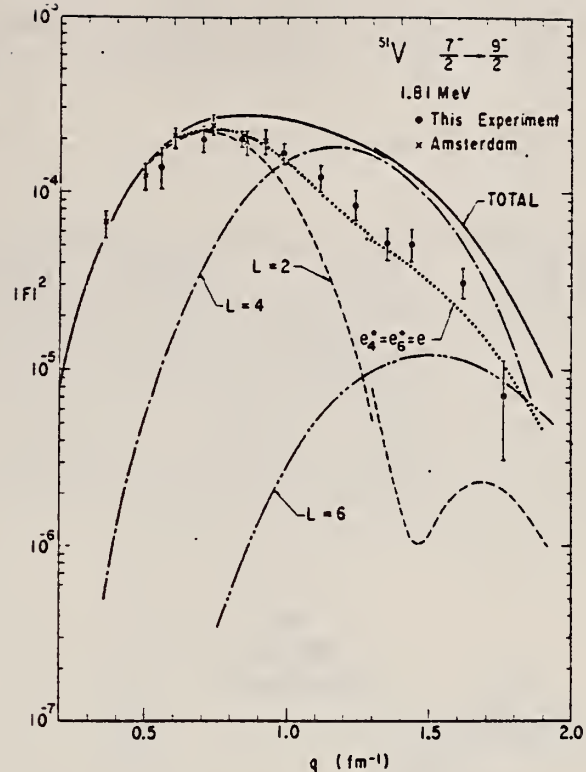


FIG. 9. Form factors for the 1.81-MeV excitation. See the caption to Fig. 6. The total curve was calculated for an effective charge of $1.88e$.

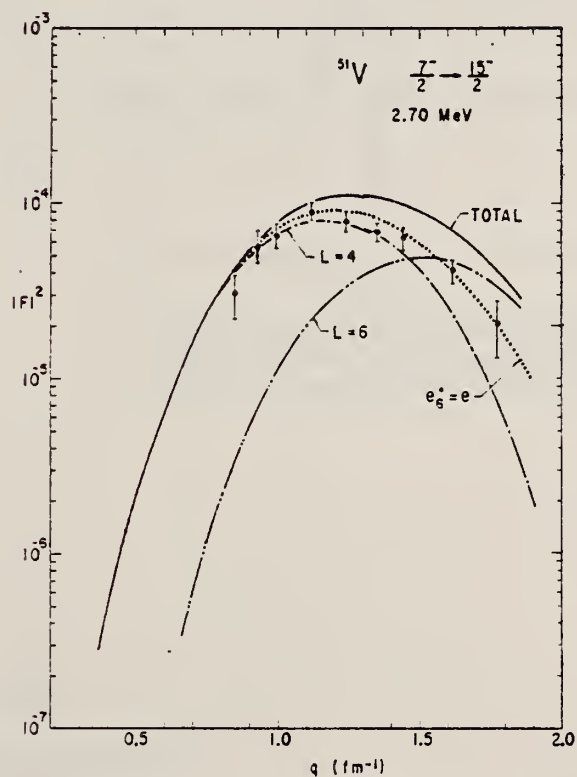


FIG. 10. Form factors for the 2.70-MeV excitation. See the caption to Fig. 6. The total curve was calculated for an effective charge of $1.69e$.

REF.	G. A. Peterson, K. Hosoyama, M. Nagao, A. Nakada, Y. Torizuka Phys. Rev. <u>C7</u> , 1028 (1973)				ELEM. SYM.	A	Z
					V	51	23
METHOD					REF. NO.		
Page 3 of 3					73 Pe 1		hmg
REACTION	RESULT	EXCITATION ENERGY'	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

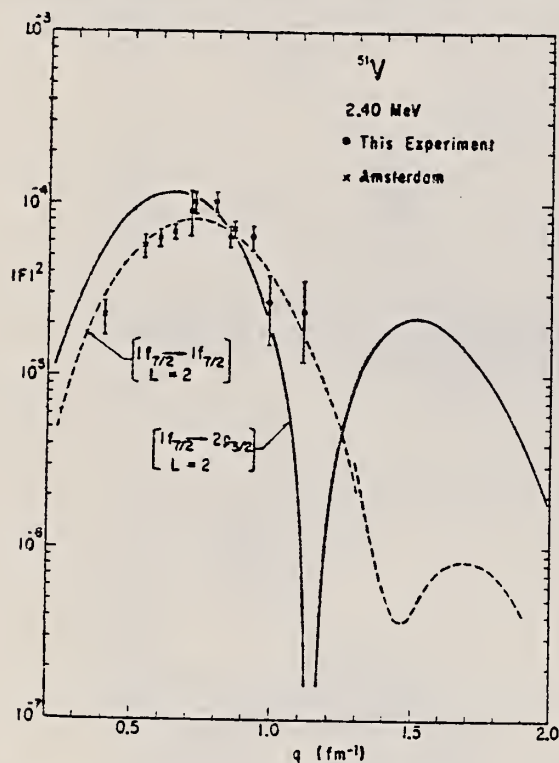


FIG. 12. $E2$ form factors for the 2.40-MeV excitation calculated for a proton transition from a $1f_{7/2}$ to a $2p_{3/2}$ configuration and for a transition within the $1f_{7/2}$ shell.

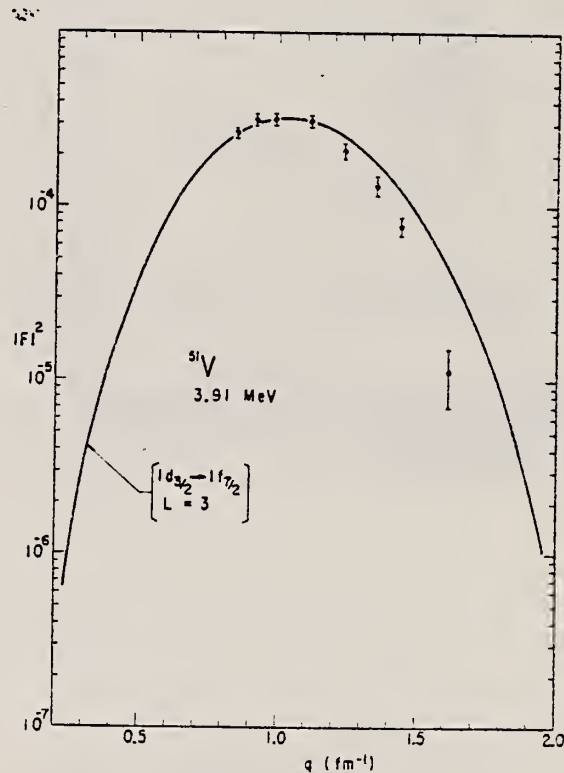


FIG. 13. $E3$ form factor for the 3.91-MeV excitation calculated for a $1d_{3/2}$ to $1f_{7/2}$ transition.

REF.

A. Veyssiere, H. Beil, R. Bergere, P. Carlos, A. Lepretre, and
A. De Miniac
Nucl. Phys. A227, 513 (1974)

ELEM. SYM.

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METHOD

REF. NO.

74 Ve 1

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
* G,N	ABX	13- 29	D	13- 29	BF3-I		4PI
** G,2N	ABX	20- 29	D	20- 29	BF3-I		4PI

* 909+

** 910

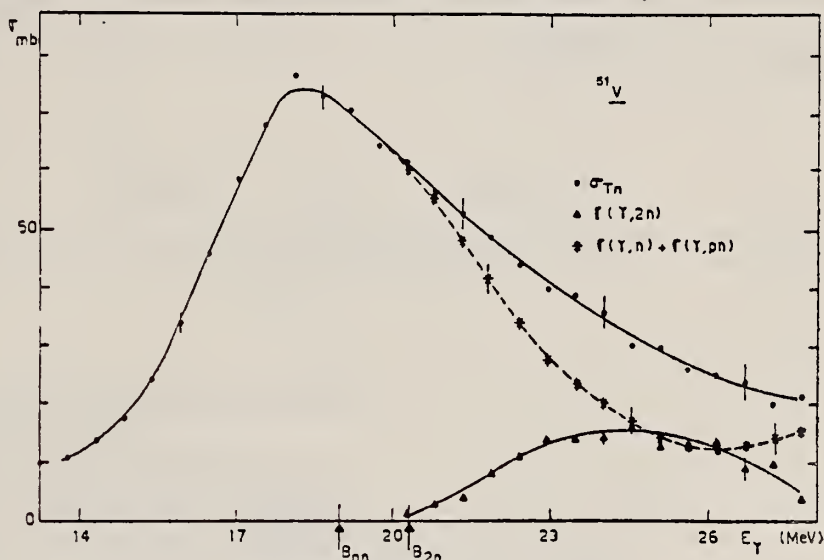


Fig. 14. Photoneutron cross sections σ_{Tn} , $[\sigma(\gamma, n) + \sigma(\gamma, 2n)]$ and $\sigma(\gamma, 2n)$ of ^{51}V .

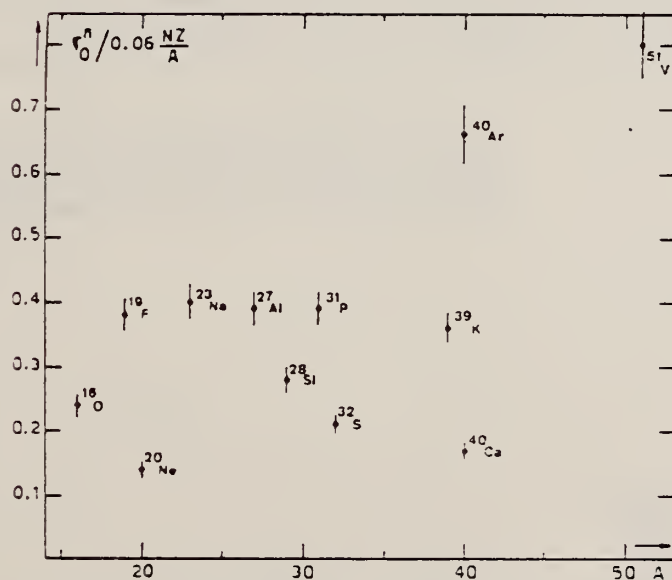


Fig. 22. Ratio of experimental integrated photoneutron cross section σ_0^n over the Thomas, Reiche and Kuhn sum rule $[0.06 NZ/A]$. Numerical values and upper integration limits E_M are taken from table 3. Also $\Delta\sigma_0^n = \pm 7\%$ for all nuclei.

(over)

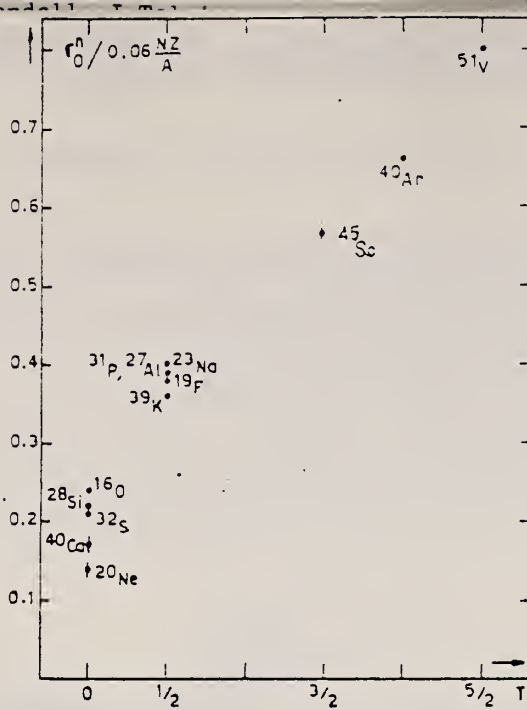


Fig. 24. The $[\sigma_0^n/(0.06 NZ/A)]$ ratio as a function of isospin T . Possible overall errors of $\pm 7\%$ are to be applied to all nuclei shown.

TABLE 3
Experimental integrated photonuclear cross sections $\sigma_0^n = \int_0^{E_M} \sigma_{Tn}(E) dE$ compared with the classical sum rule $[0.06 NZ/A]$ of Thomas, Reich and Kuhn

	$T = 0$					$T = \frac{1}{2}$					$T = \frac{3}{2}$	$T = 2$	$T = \frac{5}{2}$
Nucleus	^{16}O	^{20}Ne	^{28}Si	^{32}S	^{40}Ca	^{19}F	^{23}Na	^{27}Al	^{31}P	^{39}K	^{45}Sc	^{40}Ar	^{51}V
σ_0^n (MeV · mb)	58 ± 4	42 ± 3	94 ± 7	98 ± 7	100 ± 7	108 ± 7	137 ± 9	153 ± 10	182 ± 12	210 ± 14	383 ± 25	393 ± 23	602 ± 42
$\sigma_0^n/(0.06 NZ/A)$	0.24	0.14	0.22	0.21	0.17	0.38	0.40	0.39	0.39	0.36	0.57	0.66	0.5
E_M (MeV)	30	26.7	30	30	29.5	29	30	30	29	30	28.1	26.7	28

REF.

C. O. Wene
Z. Phys. A272, 77 (1975)

ELEM. SYM.

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METHOD

REF. NO.

75 We 4

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REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	ABX	18	D	18	SCD-D		90

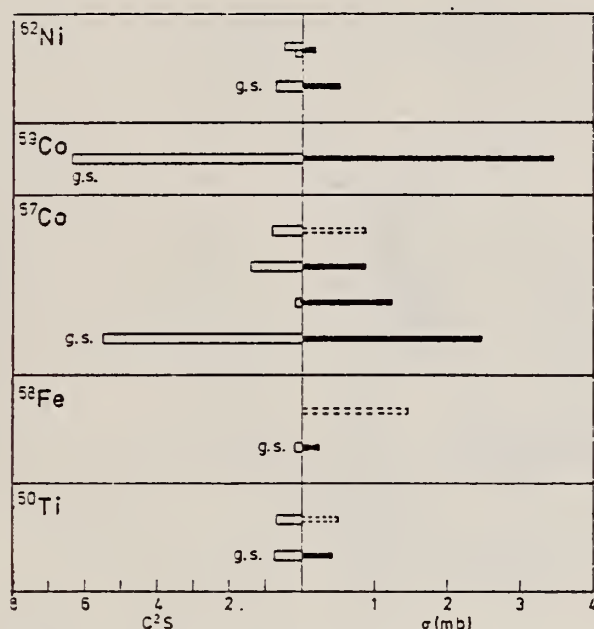
18 = 17.6 MEV

Fig. 5. Correlation between the spectroscopic factors and the cross-sections measured in this work. Open staples indicate $l_p = 3$ pick-up and cross hatched staples $l_p = 1$ pick-up. Dashed staples indicate that the cross section is uncertain due to the subtraction of a large back-ground

Table 2

Daughter nucleus	Level		σ^a (mb)
	(MeV)	J^π	
^{44}Ca	0	0^+	$\leq 0.2^b$
	1.16	2^+	$\leq 0.5^b$
^{50}Ti	0	0^+	0.41 ± 0.05
	2.68	4^+	$(0.5)^c$
^{58}Fe	0	0^+	0.23 ± 0.08
	3.24?	$0^-?$	$(1.5)^c$
^{57}Co	0	$7/2^-$	2.5 ± 0.2^d
	1.76	$3/2^-$	1.2 ± 0.3
	1.90	$7/2^-$	0.9 ± 0.2
	2.31	$7/2^-$	$(0.9)^c$
^{59}Co	0	$7/2^-$	3.5 ± 0.8
^{62}Ni	0	0^+	0.51 ± 0.09
	1.18	2^+	0.2 ± 0.1

^a The quoted errors are only those due to counting statistics.

^b Confidence level 95%.

^c Uncertain because of large background.

^d $\sigma = 2.4$ mb from [43].

43. Miyase, H., Oikawa, S., Suzuki, A., Uegaki, J., Saito, T., Sugawara, M., Shoda, K.: The photoproton reactions of Ni-isotopes. In: Proc. Int. Conf. Photoneuclear Reactions and Applications, Vol. I, p. 553. Livermore, USA 1973 (see Ref. 13)

REF. I. Blomqvist, P. Janecek, G.G. Jonsson R. Petersson,
H. Dinter and K. Tesch
Z. Physik A278, 83 (1976)

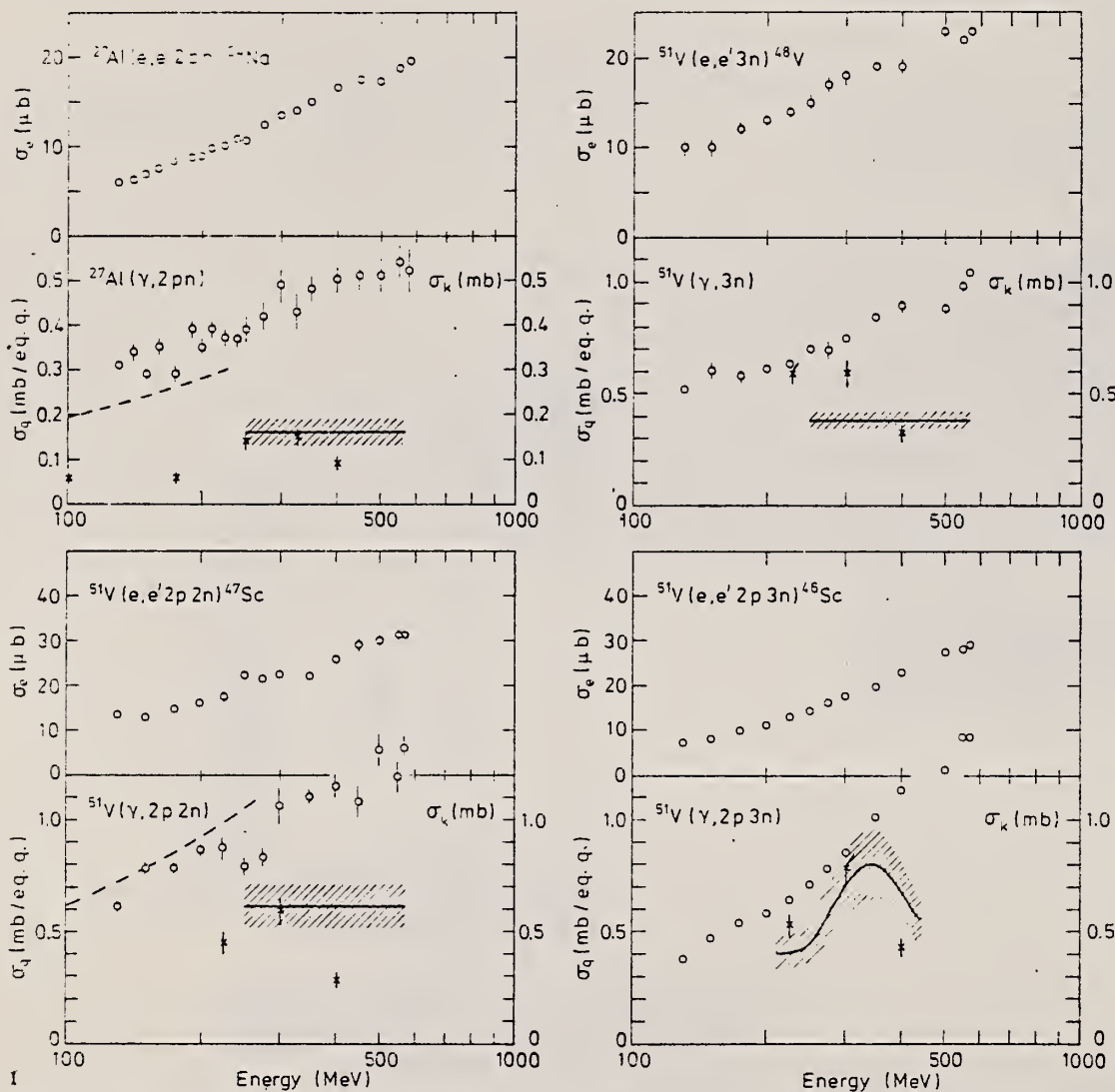
ELEM. SYM.	A	Z
V	51	23
REF. NO.		
76 B1 12		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,SPL	ABY	THR - 580	C	130-580	ACT-I		4PI
E,SPL	ABY	THR - 580	C	130-580	ACT-I		4PI

Cross sections for some electro- and photoinduced spallation reactions on ^{27}Al and ^{51}V have been measured in the energy region 130-580 MeV with the activation method. The cross sections per photon are compared to Monte-Carlo calculations based on a cascade-evaporation model. The electrodisintegration cross sections are compared to calculations based on the Dalitz formalism for virtual photon spectra.

GIVES YLD RATIO G/E



Figs. 1 and 2. Experimental cross sections σ_e and σ_q versus energy for different reactions on ^{27}Al and ^{51}V . The cross sections σ_q deduced from σ_e are given by the solid drawn curves, the hatched areas showing the uncertainty. Dashed curves show σ_q calculated from the low-energy data in Reference 11. Crosses give σ_q calculated with Monte-Carlo method

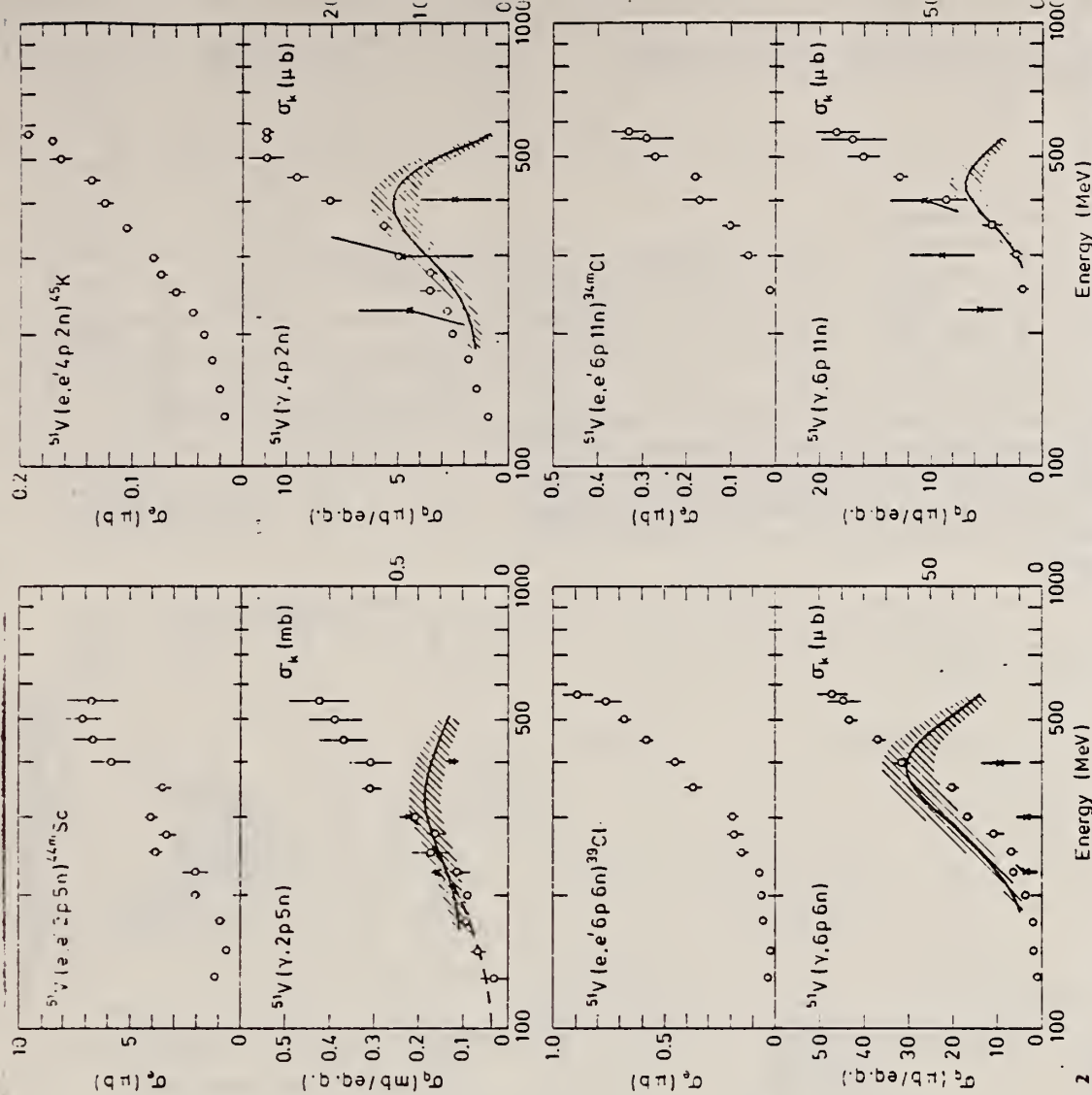
11 Meyer, R.A., Walters, W.B., Hummel, J.P.: Nucl. Phys. A122, 606 (1968)

(over)

(REV. 7-14-64)
USCOMM-NBS-DC

PHOTONUCLEAR DATA SHEET 200

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS



Figs. 1 and 2. Experimental cross sections σ_q and σ_k versus energy for different reactions on ^{27}Al and ^{51}V . The cross sections σ_q deduced from σ_k are given by the solid drawn curves, the hatched areas showing the uncertainty. Dashed curves show σ_q calculated from the low-energy σ_k in Reference 11. Crosses give σ_k calculated with Monte-Carlo method

¹¹Meyer, R.A., Walters, W.B., Hummel, J.P.: Nucl. Phys. A122, 606 (1968)

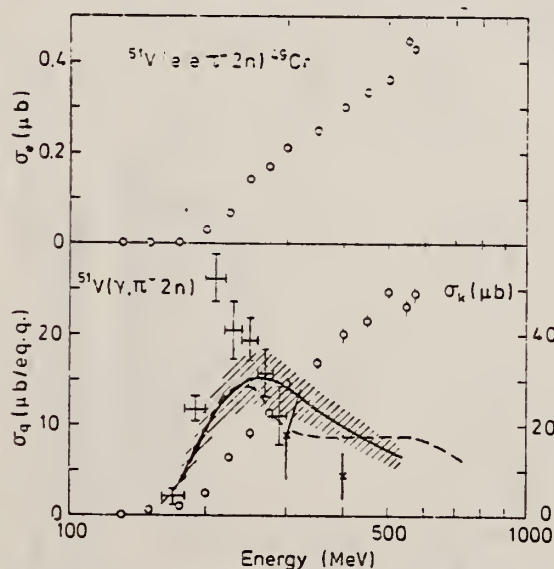


Fig. 3. Experimental and calculated cross sections for the reaction $^{51}\text{V}(\gamma, \pi^- 2n)^{49}\text{Cr}$; see caption to Figures 1-2. \pm show the corrected σ_k by Meyer and Hummel [16], the dashed curve the corrected σ_k by Nydahl and Forkman [17]

201

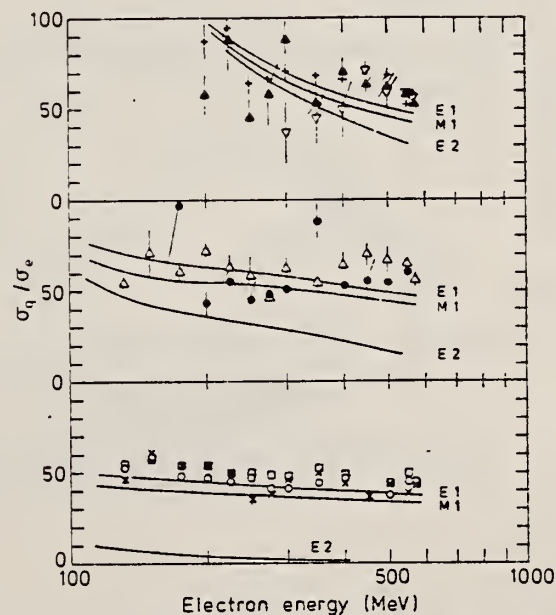


Fig. 5. The ratio σ_q/σ_k versus electron energy for different reactions on ^{51}V . \circ $3n$ emitted, \times $2p 2n$, \square $2p 3n$, \bullet $2p 5n$, Δ $4p 2n$, $+$ $\pi^- 2n$, \blacktriangle $6p 6n$, ∇ $6p 11n$. The curves show calculated cross-section ratios for $\pi^- 2n$ (top), $2p 5n$ (middle), $2p 2n$ (bottom)

¹⁶Meyer, R.A., Hummel, J.P., Phys. Rev. 140, B48 (1965)

¹⁷Nydahl, G., Forkman, 2: Nucl. Phys. B7, 97 (1968)

REF.

B. Bulow, B. Johnsson, M. Nilsson and B. Forkman
Z. Physik A278, 89 (1976)

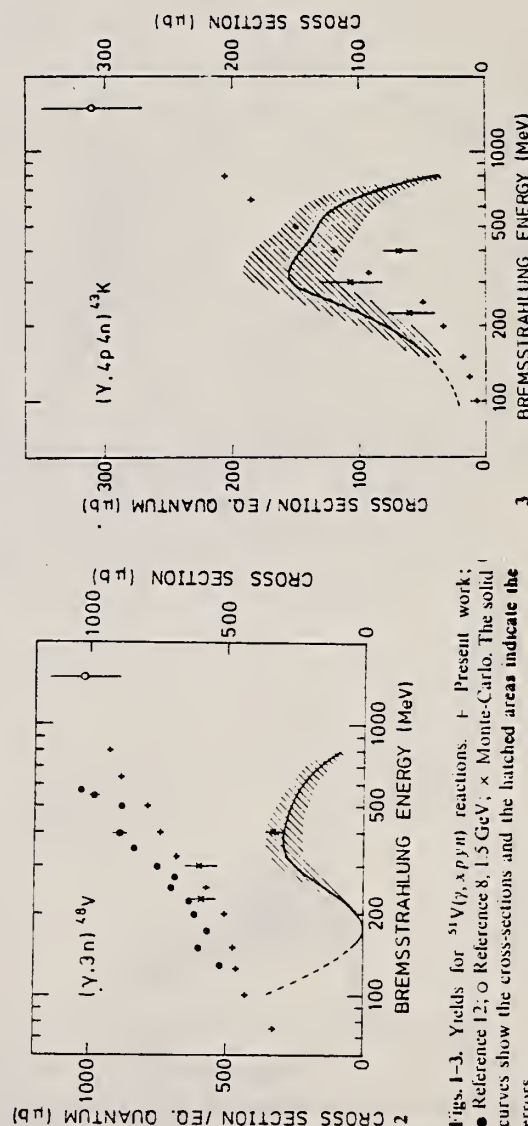
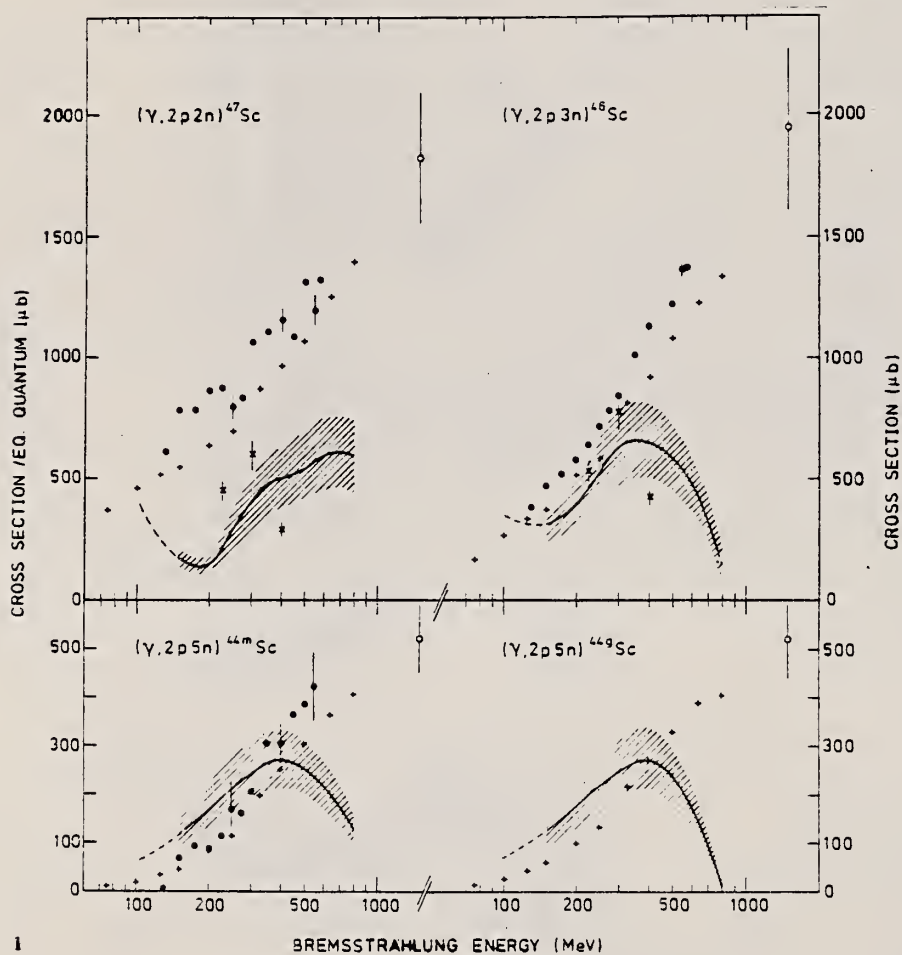
ELEM. SYM.	A	Z
V	51	23
REF. NO.		egf
76 Bu 11		

Comment: Table of cross section results

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, JPKN	ABX	THR - 800	C	75-800	ACI-I		4PI

The yields of $^{51}\text{V}(\gamma, xpy n)$ reactions have been measured at maximum bremsstrahlung energies from 75 to 800 MeV. Mean cross sections have been deduced, compared to Monte-Carlo calculations and analysed with a semiempirical Rudstam formula. Total isobaric mean cross sections and an N/Z dispersion curve in the mass region $A=42-48$ have been obtained. The results are in agreement with cascade-evaporation theory and with earlier data obtained with photons and protons.

J=2-11, K-2-16



Figs. 1-3. Yields for $^{51}\text{V}(\gamma, xpy n)$ reactions. + Present work; ● Reference 12; ○ Reference 8, 1.5 GeV, × Monte-Carlo. The solid curves show the cross-sections and the hatched areas indicate the errors.

(OVER)

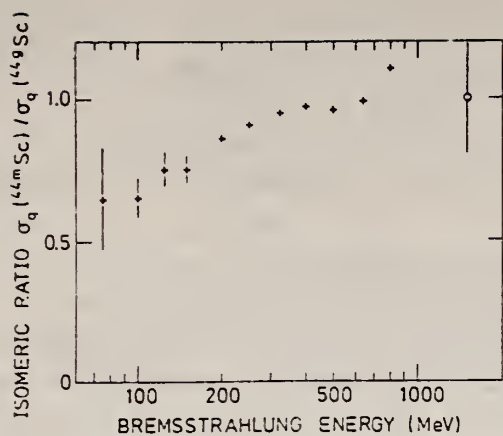


Fig. 4. Isomeric ratios vs. bremsstrahlung energy. + present work, o Reference 8

⁸Kumbartzki, G., Kim, U.: Nucl. Phys. A176, 23 (1971)

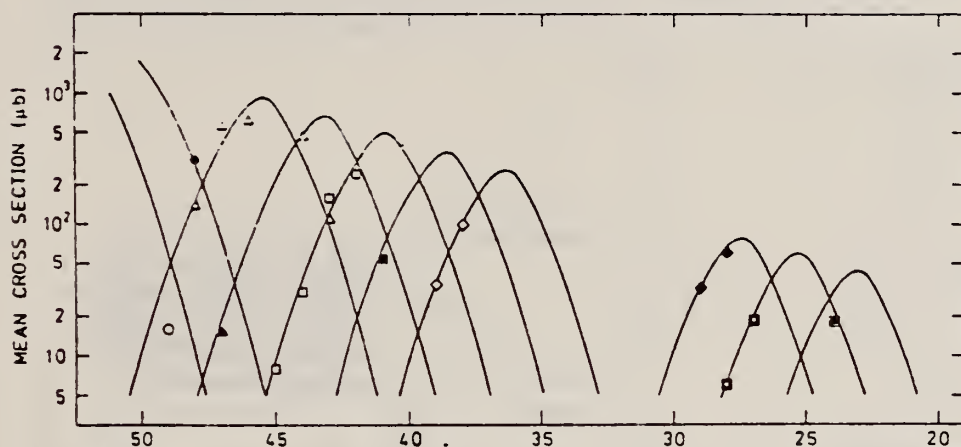


Fig. 5. Mean cross-section distributions for different elements, o Cr, • V, \$\Delta\$ Sc, \$\blacktriangle\$ Ca, \$\square\$ K, \$\blacksquare\$ Ar, \$\diamond\$ Cl, \$\blacklozenge\$ Al, \$\square\$ Mg, \$\blacksquare\$ Na

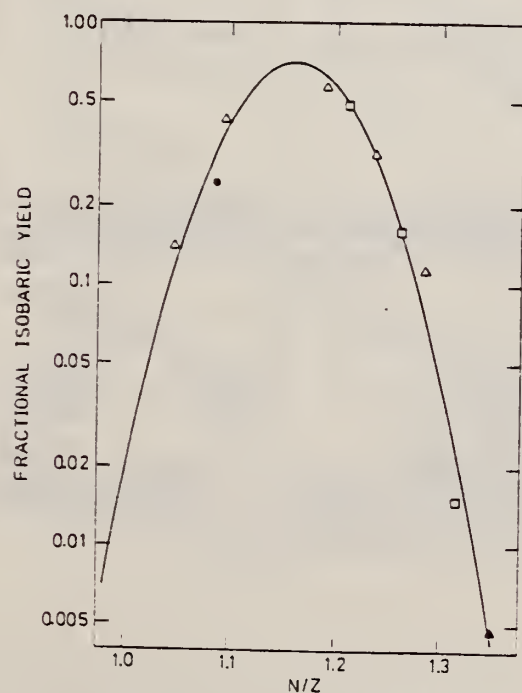


Fig. 6. N/Z dispersion of products in the mass region 42-48 calculated from mean cross-sections in the energy range 250-400 MeV. The solid line shows the Gaussian curve giving a best fit to the data. The symbols used are: • V, \$\Delta\$ Sc, \$\blacktriangle\$ Ca, \$\square\$ K

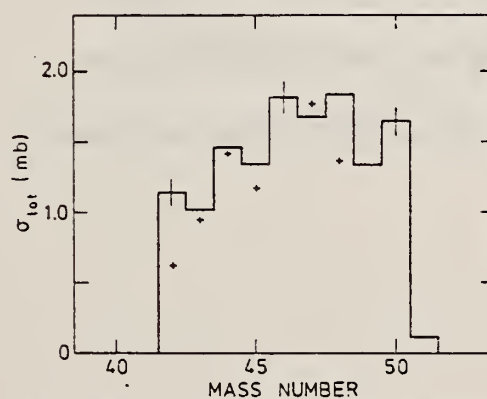


Fig. 7. Total isobaric cross-sections. The plus signs represent the experimental results and the histogram displays arithmetic mean values from Monte-Carlo calculations

REF. A. S. Danagulyan, N. A. Demekhina
Yad. Fiz. 24, 681 (1976)
Sov. J. Nucl. Phys. 24, 355 (1976)

ELEM. SYM.	A	Z
V	51	23

METHOD

REF. NO.

76 Da 4

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, NA24	ABX	THR* 5	C	2* 5	ACT-I		4PI

*ENERGY, GEV

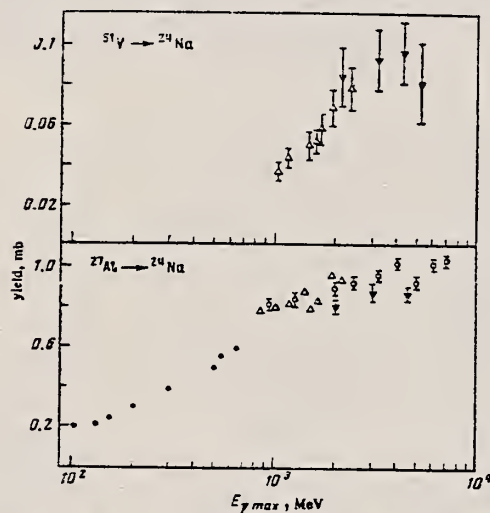


FIG. 1. Yields of the reactions. Points: ∇ —present work, \bullet —Ref. 10, Δ —Ref. 3, \circ —Ref. 9.

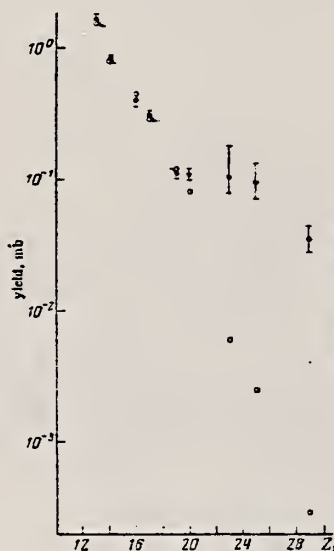


FIG. 2. Yield values and theoretical values according to the modified Rudstam formula as a function of the target charge number Z_1 . Points: \bullet —experiment, \circ —theory.

³G. Kumbartzki et al., Nucl. Phys. A176, 23 (1971).

⁹G. Andersson et al., Nucl. Phys. A197, 44 (1972).

¹⁰I. Blomqvist et al., Nucl. Phys. A162, 193 (1971).

TABLE I. Experimental yields and reaction cross sections obtained in the measurements at the Erevan electron accelerator.

Target nucleus	Reaction yield, mb					Reaction cross section, mb
	$E_{\gamma \text{ max}}$ GeV					
	2	3	4	4.5	5	
^{27}Al	0.81 ± 0.08	0.87		0.87		0.07213 ± 0.0346
^{28}Si	0.27 ± 0.02	0.28		0.29		0.0267 ± 0.013
^{32}S	0.24 ± 0.02	0.22		0.27		0.0323 ± 0.0155
Cl	0.28 ± 0.03	0.30		0.28		
^{39}K	0.1 ± 0.01	0.125		0.15		0.06 ± 0.0288
^{40}Ca	0.086 ± 0.01	0.09		0.115		0.035 ± 0.0168
^{41}V	0.085 ± 0.02	0.094 ± 0.02	0.095 ± 0.02		0.082 ± 0.025	0.019
^{55}Mn	0.079 ± 0.02	0.075 ± 0.02	0.087 ± 0.017		0.088 ± 0.015	0.01076 ± 0.0056
Cu	0.029 ± 0.008	0.037 ± 0.007	0.036 ± 0.007		0.034 ± 0.007	0.00547 ± 0.0025

Note. The reaction cross sections have been calculated in the $1/E$ approximation of the bremsstrahlung spectrum.

REF.

K. Nakamura, S. Hiramatsu, T. Kamae, H. Muramatsu,
N. Izutsu, Y. Watase
Nucl. Phys. A271, 221 (1976)

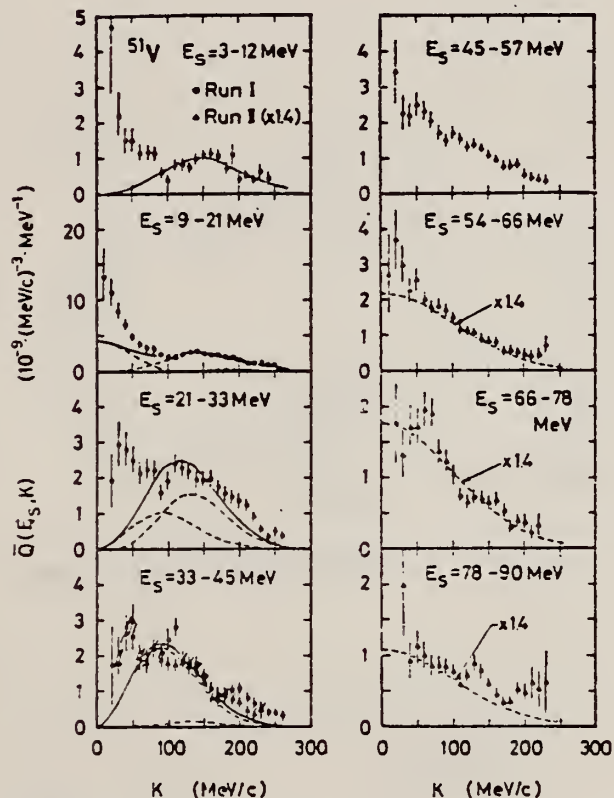
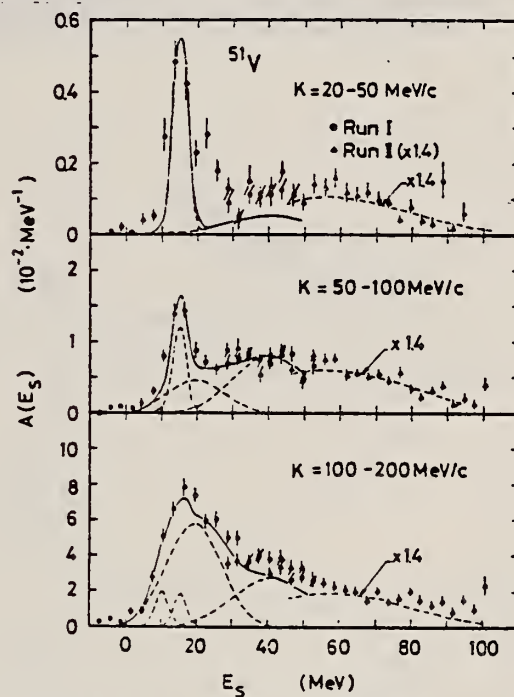
ELEM. SYM.	A	Z
V	51	23

METHOD	REF. NO.	
	76 Na 3	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
$E, E/P$	SPC	$0^{+}130$	D	700	MAG-D		DST

Abstract: Information on proton hole states has been obtained for ^{27}Al , ^{40}Ca and ^{51}V through the $(e, e'p)$ reaction. Lower-lying hole states have been identified. For ^{40}Ca an extensive analysis has been performed to study the structure of the $1s$ hole state. For ^{27}Al and ^{51}V , the properties of the $1s$ hole states have also been determined. The separation energies of the $1p$ and $1s$ states seem to be constant (40 and 60 MeV, respectively) for $A > 30$.

*SEPARATION ENERGY

Fig. 5b. Recoil momentum distributions for ^{51}V . The curves are as in fig. 4a.Fig. 5a. Proton separation energy spectra for ^{51}V . The curves are as in fig. 4a.

(over)

TABLE 6
Results of the PWIA analysis

Nucleus	α	Z_s'	Peak energy (MeV)	Width (FWHM) ^{a)} (MeV)	Oscillator const (MeV/c)
²⁷ Al	2s	0.12 ± 0.01	14.3 ± 0.2	4 ± 3	82 ± 4
	1d	1.6 ± 0.1	14.0 ± 0.6	12 ± 2	91 ± 1
	1p	2.4 ± 0.2	34 ± 1	31 ± 3	100 ± 1
	1s ^{b)}		57 ± 3	31 ± 9	148 ± 4
⁴⁰ Ca	1d _{3/2}	1.1 ± 0.3	10.9 ± 0.7	9 ± 1	76 ± 4
	2s	0.9 ± 0.1	14.4 ± 0.3	13 ± 1	83 ± 3
	1d _{5/2}	1.5 ± 0.3	19.0 ± 1.1	10 ± 1	93 ± 4
	1p	1.8 ± 0.4	35 ± 1	21 ± 3	85 ± 3
	1s ^{b)}		59 ± 3	34 ± 10	144 ± 6
⁵¹ V	1f	0.4 ± 0.1	10.3 ± 1.1	5 ± 3	115 ± 8
	2s	0.3 ± 0.1	15.1 ± 0.2	5 ± 2	99 ± 5
	1d	1.7 ± 0.3	19.5 ± 0.5	19 ± 2	94 ± 6
	1p	1.1 ± 0.1	40 ± 1	25 ± 4	91 ± 4
	1s ^{b)}		60 ± 3	36 ± 11	143 ± 4

The errors are statistical only except for those assigned to the peak energies and widths for the 1s states.

^{a)} The experimental energy resolution (≈ 7 MeV) is not unfolded.

^{b)} Parameters were determined from the fit to the data of run II.

REF.

I. Blomqvist, P. Janecek, G. G. Jonsson, H. Dinter,
K. Tesch, N. Freed, P. Ostrander
Phys. Rev. C15, 988 (1977)

ELEM. SYM.

A

Z

V

51

23

METHOD

REF. NO.

77 B1 2

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,PI+	ABX	150-577	D	131-577	ACT-I		4PI
G,PI+	ABY	150-577	D	131-577	ACT-I		4PI
E,PI-	ABY	150-577	D	131-577	ACT-I		4PI
G,PI-	ABY	150-577	D	131-577	ACT-I		4PI

Cross sections for electroproduction and photoproduction of charged pions on ^{27}Al and ^{51}V have been measured in the energy region 130-580 MeV by use of the activation method. Special care has been taken to subtract out background yields. Photoproduction cross sections have been calculated from the region just above threshold to the tail of the (3,3) resonance. π -nucleus final state interactions are taken into account through optical potentials. Calculated photoproduction cross sections are decomposed into multipoles which are used to derive relative bremsstrahlung-induced to electron-induced yields. The pronounced effect of final state interactions is pointed out and discussed.

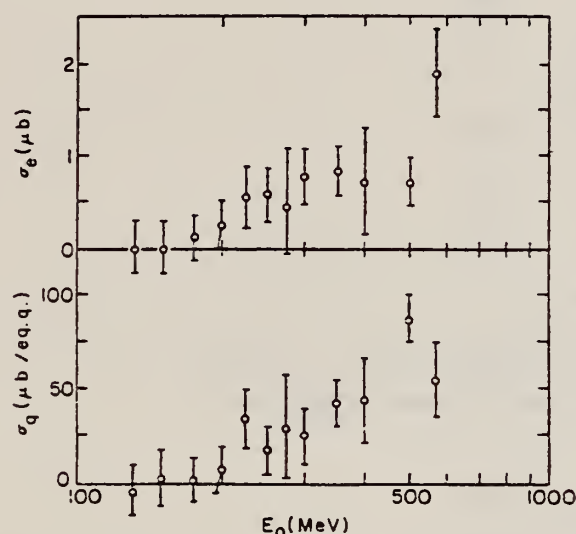


FIG. 5. σ_e and σ_q for the reactions $^{51}\text{V}(\gamma, \pi^-)^{51}\text{Cr}$ and $^{51}\text{V}(e, e' \pi^-)^{51}\text{Cr}$. See Fig. 3.

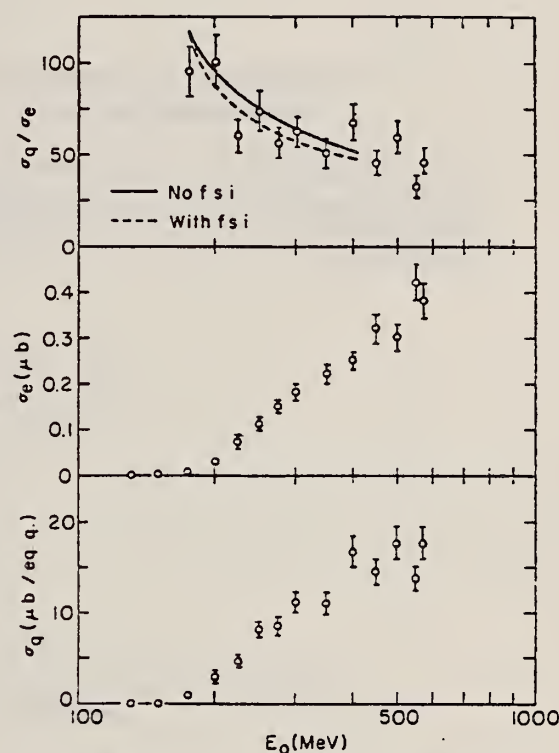


FIG. 4. Same as Fig. 3 for the reactions $^{51}\text{V}(\gamma, \pi^+)^{51}\text{Ti}$ and $^{51}\text{V}(e, e' \pi^+)^{51}\text{Ti}$.

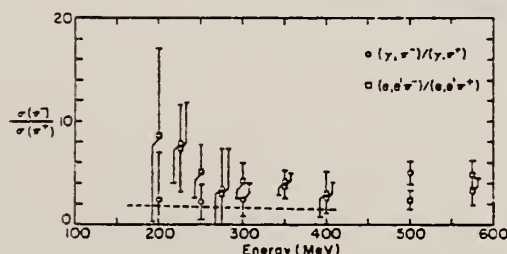


FIG. 11. Ratio of negative to positive pion electroproduction and photoproduction cross sections on ^{51}V . The dashed line is the calculated ratio with fsi absent.

(over)

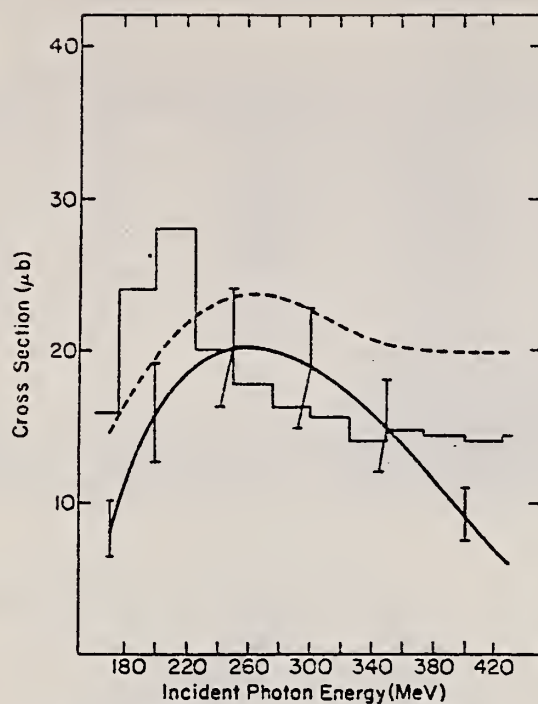


FIG. 7. Experimental cross sections per photon for the reaction $^{51}\text{V}(\gamma, \pi^+)^{51}\text{Ti}$. The solid curve with error bars is the result of the present work. The dashed curve is the work of Ref. 13. The histogram represents the data of Ref. 14.

- ¹³G. Nydahl et al., Nucl. Phys. B7, 97 (1968).
¹⁴I. Blomqvist et al., Nucl. Phys. A162, 193 (1971).

ELEV. SYN.	A	Z
V	51	23
REF. NO.		egf
77 Da 3		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,SPL	ABY	THR * 5	C	2*5	ACT-I		4PI

*ENERGY, GEV

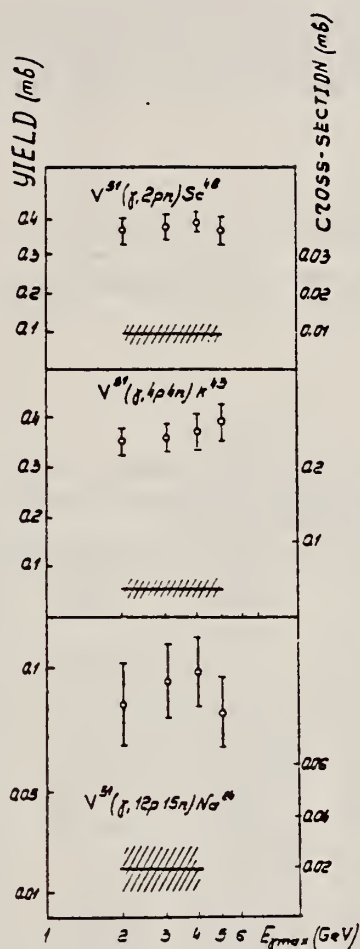


Fig. 2. Yields of some spallation reactions in ^{51}V , ^{55}Mn and Cu targets. The cross section estimates are obtained in the $1/E$ approximation for bremsstrahlung.

(over)

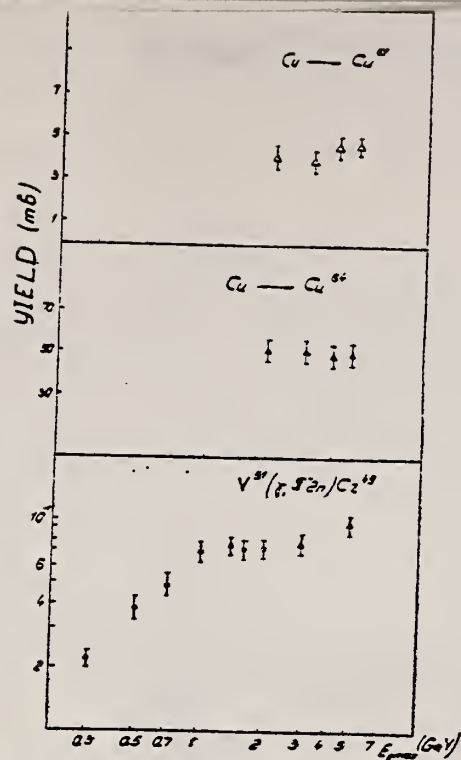


Fig. 1. Characteristic curves of some simple reaction yields.

TABLE 2
Photospallation reaction yields (mb per eq. quantum)

Residual nuclei	Reaction yields (mb)					Reaction cross sections (mb)
	$E_{\gamma, \max} = 2 \text{ GeV}$ (exp)	3 GeV (exp)	4 GeV (exp)	5 GeV (exp)	5 GeV (cal)	
^{40}Cr		0.081 ± 0.008	$^{51}\text{V target}$			
^{48}V	1.15 ± 0.13	1.19 ± 0.13	1.25 ± 0.15	1.2 ± 0.2	1.13	0.0798 ± 0.038
^{48}Sc	0.37 ± 0.04	0.38 ± 0.04	0.39 ± 0.03	0.37 ± 0.04	0.464	0.0092 ± 0.0044
^{47}Sc	1.68 ± 0.1	1.65 ± 0.08	1.74 ± 0.1	1.6 ± 0.2	1.44	
^{46}Sc	2.05 ± 0.3	2.14 ± 0.3	2.03 ± 0.2	2.0 ± 0.3	2.95	
^{44}Sc	0.55 ± 0.06	0.45 ± 0.06	0.57 ± 0.07	0.56 ± 0.07	1.03	
^{44m}Sc	0.47 ± 0.03	0.47 ± 0.03	0.44 ± 0.04	0.46 ± 0.04		
^{43}Sc	0.2 ± 0.025	0.191 ± 0.025	0.217 ± 0.02	0.185 ± 0.02	0.25	
^{44}K			≤ 0.027		0.093	
^{43}K	0.34 ± 0.03	0.351 ± 0.03	0.36 ± 0.04	0.38 ± 0.04	0.335	0.0345 ± 0.0166
^{42}K	0.6 ± 0.06	0.54 ± 0.06	0.55 ± 0.06	0.53 ± 0.08	0.88	
^{39}Cl	0.06 ± 0.009	0.068 ± 0.009	0.061 ± 0.009	0.074 ± 0.01	0.077	0.0086 ± 0.004
^{38}Cl		0.14 ± 0.02	0.19 ± 0.04	0.17 ± 0.02	0.24	
^{24}Na	0.085 ± 0.2	0.094 ± 0.02	0.098 ± 0.02	0.082 ± 0.015	0.04	0.019 ± 0.009

Calculated values are obtained using Rudstam's formula. Cross section estimates are made in the $1/E$ approximation.

REF.

V. di Napoli, M.L. Terranova, H.G. de Carvalho, J.B. Martins
J.D. Pinheiro Filo and O.A.P. Tavares
J. Inorg. Nucl. Chem. **39**, 1727 (1977)

ELEM. SYM.	A	Z
V	51	23

METHOD

REF. NO.

77 Di 6

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,3N	ABY	THR-999	C	300-999	ACT-I		4PI

Abstract—Cross sections per equivalent quantum, in the energy range 0.3–1.0 GeV, have been measured for $^{209}\text{Bi}(\gamma, 2n)$, $^{209}\text{Bi}(\gamma, 3n)$, $^{209}\text{Bi}(\gamma, 4n)$, $^{59}\text{Co}(\gamma, 2n)$, $^{59}\text{Co}(\gamma, 3n)$, $^{59}\text{Co}(\gamma, 4n)$ and $^{51}\text{V}(\gamma, 3n)$ reactions. From the calculated mean absolute cross sections and the data already available in literature for (γ, xn) reactions ($x \geq 1$), a cross section formula has been deduced which reproduces, within a factor of two, most of the experimental cross sections for target nuclei ranging between ^9Be and ^{238}U .

999=1 GeV

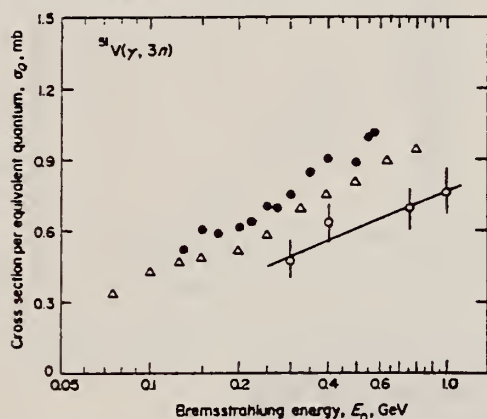


Fig. 1. Yields for the $^{51}\text{V}(\gamma, 3n)$ reaction. Open circles present experiment; filled circles from Ref. [17]; open triangles from Ref. [18]. The straight line is a least-squares fit of the present work experimental points.

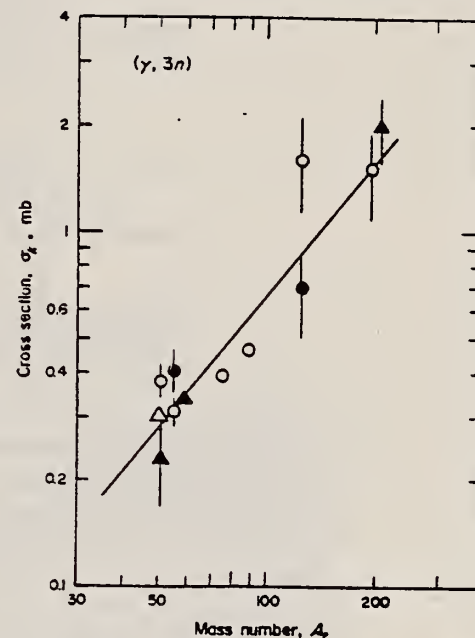


Fig. 5. The same as in Fig. 4 for the $(\gamma, 3n)$ reactions. Filled circles are taken from our earlier experiments: ^{55}Mn , Ref. [7]; ^{127}I , Ref. [3]. Open circles: ^{51}V , Ref. [17]; ^{55}Mn , Ref. [11]; ^{75}As , Ref. [12]; ^{89}Y , Ref. [14]; ^{127}I , Ref. [9, 10, 13]; ^{197}Au , Ref. [15]. Open triangle: ^{51}V , Ref. [18]. Filled triangles are the results of the present work for ^{51}V , ^{59}Co and ^{209}Bi . The straight line is a least-squares fit of the experimental points.

Table 2. Mean absolute cross sections for the (γ, xn) reactions, with $1 < x < 5$, in complex nuclei at intermediate energies.

Target nucleus	Reaction	Energy-range (GeV)	Ref.	Cross section, σ_x (mb)	
				(Experimental)	(Calc.†)
⁹ Be	$(\gamma, 2n)$	0.3–1.0	8	0.021 ± 0.002	0.007
¹² C	$(\gamma, 2n)$	0.2–0.8	16	0.0277 ± 0.0004	0.025
¹⁶ O	$(\gamma, 2n)$	0.2–0.8	16	0.0113 ± 0.0003	0.072
⁵¹ V	$(\gamma, 3n)$	0.3–1.0	This work	0.23 ± 0.06	0.268
		0.25–0.60	17	0.38 ± 0.04	0.268
		0.25–0.80	18	0.307 ± 0.012	0.268
		0.3–1.0	7	0.41 ± 0.05	0.33
⁵⁵ Mn	$(\gamma, 3n)$	0.3–0.8	11	0.311 ± 0.016	0.33
		0.3–1.0	7	0.053 ± 0.004	0.079
		0.3–1.0	7	1 ± 1	1.3
⁵⁹ Co	$(\gamma, 2n)$	0.4–1.0	This work	1 ± 1	1.3
	$(\gamma, 3n)$	0.3–1.0	This work	0.337 ± 0.007	0.4
	$(\gamma, 4n)$	0.3–1.0	This work	0.06 ± 0.01	0.1
	$(\gamma, 4n)$	0.3–1.0	This work	0.06 ± 0.01	0.1
⁷⁵ As	$(\gamma, 3n)$	0.2–0.9	12	0.39	0.7
	$(\gamma, 4n)$	0.2–0.9	12	0.24	0.24
⁸⁹ Y	$(\gamma, 3n)$	0.25–1.0	14	0.47	1.0
¹⁰³ Rh	$(\gamma, 2n)$	0.4–0.9	4, 6	5.1 ± 2.4	2.7
¹²⁷ I	$(\gamma, 2n)$	0.1–0.8	9	$7.4 \pm$	3.4
		0.3–1.0	3	20 ± 7	3.4
	$(\gamma, 3n)$	0.3–1.0	3	0.7 ± 0.2	1.9
		0.25–0.9	9, 10, 13	1.6 ± 0.5	1.9
	$(\gamma, 4n)$	0.25–0.9	9, 10, 13	1.4 ± 0.4	1.0
	$(\gamma, 2n)$	0.3–0.9	15	2 ± 2	5.2
¹⁹⁷ Au	$(\gamma, 2n)$	0.3–1.0	5	7 ± 5	5.2
		0.3–0.9	15	1.5 ± 0.4	3.6
	$(\gamma, 3n)$	0.3–1.0	This work	6 ± 1	5.5
²⁰⁹ Bi	$(\gamma, 2n)$	0.3–1.0	This work	2.0 ± 0.4	3.8
	$(\gamma, 3n)$	0.3–1.0	This work	1.3 ± 0.2	2.5
	$(\gamma, 4n)$	0.3–1.0	This work	1.3 ± 0.2	2.5

†Calculated values according to eqn (12)

‡Deduced value from the interpolated σ_Q curve as indicated in Ref. [9].

- V. di Napoli, F. Dobici, F. Salvetti and H. G. de Carvalho, *Nuovo Cimento* 43B, 1 (1967).
- V. di Napoli, D. Margadonna, F. Salvetti, H. G. de Carvalho and J. B. Martins, *Lett. Nuovo Cimento* 1, 308 (1969).
- V. di Napoli, A. M. Lacerenza, D. Margadonna, F. Salvetti, H. G. de Carvalho and J. B. Martins, *Lett. Nuovo Cimento* 1, 65 (1971).
- C. Aurisicchio, V. di Napoli, F. Salvetti and M. L. Terranova, *Gazz. Chim. Ital.* 102, 378 (1972).
- H. G. de Carvalho, J. B. Martins, O. A. P. Tavares, V. di Napoli, F. Salvetti, *Proceedings of the International Conference on Photoneuclear Reactions and Applications*, Pacific Grove, Cal., Sect. 8C5-1 (1973); V. di Napoli, J. B. Martins, G. Persichelli and M. L. Terranova, *Lett. Nuovo Cimento* 11, 179 (1974).
- V. di Napoli, M. L. Terranova, H. G. de Carvalho and J. B. Martins, *Gazz. Chim. Ital.* 104, 463 (1974).
- G. G. Jonsson and B. Forkman, *Nucl. Phys.* A107, 52 (1968).
- G. G. Jonsson, B. Forkman and K. Lindgren, *Phys. Lett.* 26B, 508 (1968).
- G. Andersson, B. Forkman and B. Friberg, Report LUNP 6901, Lund Institute of Technology, Lund University, p. 4, Sect. 8, 1969 (unpublished).
- G. Andersson and B. Forkman, Annual Report, University of Lund, Lund Institute of Technology, p. 48, (1970) (unpublished).
- G. G. Jonsson and B. Persson, *Nucl. Phys.* A153, 32 (1970).
- J. Sternby, Report LUNP 7011, Lund Institute of Technology, Lund University, September 1970 (unpublished). Also quoted in G. G. Jonsson and K. Lindgren, *Phys. Scr.* 7, 49 (1973).
- K. Lindgren and G. G. Jonsson, *Nucl. Phys.* A166, 643, (1971).
- B. Johnsson, M. Nilsson and K. Lindgren, University of Lund Report LUNFD6/NFFR-3005/1-18/, LUTFD 6/(TFKF-3003/1-18/, October (1976).
- L. Blomqvist, P. Janeček, G. G. Jonsson, R. Petersson, H. Dinter and K. Tesch, *Z. Physik* A278, 83 (1976).
- B. Bülow, B. Johnsson, M. Nilsson and B. Forkman, *Z. Physik* A278, 89 (1976).
- G. G. Jonsson and K. Lindgren, *Phys. Scr.* 7, 49 (1973).
- G. G. Jonsson and K. Lindgren, *Nucl. Phys.* A141, 355 (1970).
- T. A. Gabriel and R. G. Alsmiller, Jr., *Phys. Rev.* 182, 1035 (1969).
- V. S. Barashenkov, F. G. Gereghe, A. S. Iljinov, G. G. Jonsson, and V. D. Toneev, *Nucl. Phys.* A231, 462 (1974).
- V. di Napoli, D. Margadonna, F. Salvetti, H. G. de Carvalho, and J. B. Martins, *Nucl. Instr. Methods* 93, 77 (1971).
- C. M. Lederer, J. B. Hollander and L. Perlman, *Table of Isotopes*, Wiley, New York (1967).
- V. di Napoli, F. Salvetti, M. L. Terranova, H. G. de Carvalho and J. B. Martins, *Phys. Rev.* C8, 206 (1973); V. di Napoli, A. M. Lacerenza, F. Salvetti, S. M. Terenzi, H. G. de Carvalho and J. B. Martins, *J. Inorg. Nucl. Chem.* 35, 1419 (1973).

REF. V.S. Kuz'menko, A.V. Mitrofanova, V.I. Noga, Yu.N. Ranyuk,
P.V. Sorokin, Yu.N. Telegin, I. Blomqvist, G.G. Jonsson,
and N. Freed
Phys. Rev. C 16, 1513 (1977)

ELEM. SYM.	A	Z
V	51	23

REF. NO.	
77 Ku 3	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,PI+	RLX	150-999	C	600-999	ACT-I		4PI

Cross sections for photoproduction and electroproduction of π^+ on ^{27}Al and ^{51}V leading to bound states in the daughter nuclei have been measured at Kharkov in the energy range 600–1200 MeV by use of the activation method. Careful comparison is made to other recent results obtained at intermediate and high energies. Agreement is found between the present data and results of earlier work carried out at Lund and DESY. Discrepancies between photoproduction data taken at different laboratories are attributed to differences between methods of background subtraction. Relative bremsstrahlung-induced to electron-induced yield ratios are compared with predictions based on the Dalitz-Yennie formalism for virtual-photon spectra.

999=1.2 GeV, Ratio σ/σ_e

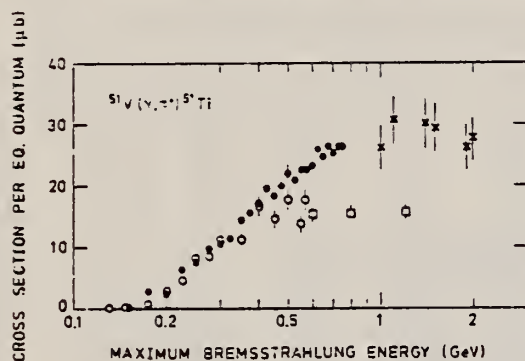


FIG. 3. Same as Fig. 2 for the reaction $^{51}\text{V}(\gamma, \pi^+)^{51}\text{Ti}$. \square , present work; \circ , Ref. 2; \bullet , Ref. 10; \times , Ref. 15.

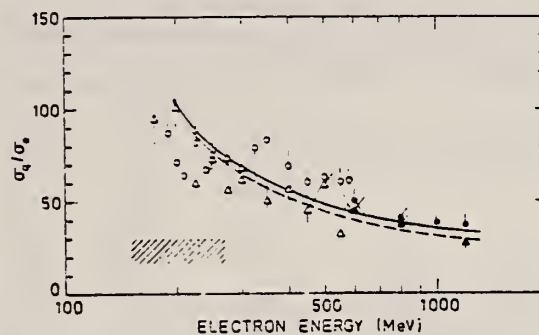


FIG. 6. The cross section ratio σ_γ/σ_e versus electron energy. $^{27}\text{Al}-^{27}\text{Mg}$: \bullet , present work; \circ , Ref. 2; hatched region, Ref. 11. $^{51}\text{V}-^{51}\text{Ti}$: \blacktriangle , present work; \triangle , Ref. 2. The solid and dashed curves are calculated results assuming E1 and M1 transitions, respectively.

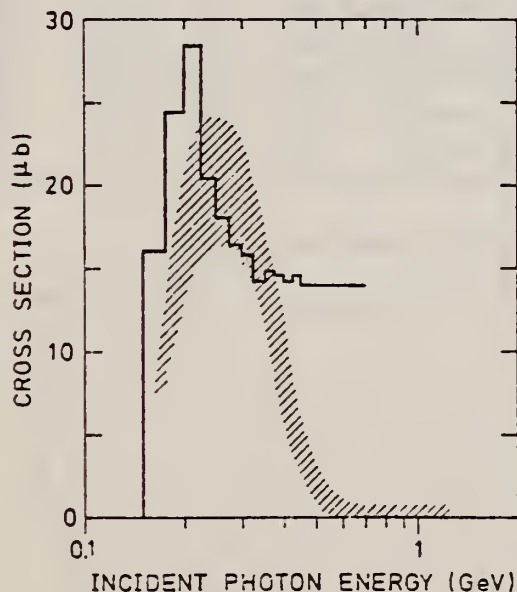


FIG. 5. Same as Fig. 4 for the reaction $^{51}\text{V}(\gamma, \pi^+)^{51}\text{Ti}$. The hatched area represents the present work with uncertainties indicated. The histogram is from Ref. 10.

- ²I. Blomqvist, P. Janecek, G.G. Jonsson, H. Dinter K. Tesch, n. Freed, and P. Ostrander, Phys. Rev. C 15, 988 (1977); DESY Report No. 76/51 (unpublished)
- ¹⁰I. Blomqvist, G. Nydahl, and B. Forkman, Nucl. Phys. A 162, 193 (1971)
- ¹¹V.I. Noga, Yu. Ranyuk, P.V. Sorokin, and V.A. Tkachenko, Yad. Fiz. 14, 904 (1971) [Sov. J. Nucl. Phys. 14, 506 (1972)]
- ¹⁵G. Kumbartzki and U. Kim, Nucl. Phys. A 176, 23 (1971)

ELEM. SYM.	A	Z
V	51	23
REF. NO.		
78 Da 13		hg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,2P5N	ABX	THR*5	C	2*5	ACT-D		4PI

*GEV, ISOMER YLD

We discuss data concerning the ratios of the yields of different isomeric states in the elements ^{44}Sc and ^{52}Mn . Experimental results are presented for measurement of the yields of $^{44g,m}\text{Sc}$ and $^{52g,m}\text{Mn}$ in disintegration of targets of ^{51}V , ^{55}Mn , and Cu by photons with energies from 2 to 5 GeV; theoretical values of yields for these elements were obtained by means of the five-parameter Rudstam formula. The pattern of formation of high-spin states in photodisintegration reactions is discussed in terms of the cascade-evaporative model.

PACS numbers: 25.20. + y, 27.40. + z

TABLE I.

Type of target	Isomeric states	Yield, mo				
		Experiment				Theory
		$E_{\gamma, \text{min}} = 2 \text{ GeV}$	3 GeV	4 GeV	5 GeV	
^{51}V	^{44g}Sc	0.47 ± 0.03	0.47 ± 0.03	0.44 ± 0.04	0.16 ± 0.04	1.03
	^{44m}Sc	0.55 ± 0.06	0.45 ± 0.06	0.57 ± 0.07	0.56 ± 0.07	
^{55}Mn	^{52g}Sc	0.45 ± 0.04	0.47 ± 0.04	0.42 ± 0.05	0.55 ± 0.05	1.3
	^{52m}Sc	0.42 ± 0.04	0.42 ± 0.04	0.55 ± 0.1	0.45 ± 0.05	
^{55}Mn	^{52g}Mn	0.49 ± 0.05	0.43 ± 0.04	0.6 ± 0.06	0.48 ± 0.05	1.34
	^{52m}Mn	0.53	0.53	0.53	0.53	
Cu	^{64g}Sc	0.25 ± 0.03	0.27 ± 0.03	0.26 ± 0.026	0.24 ± 0.03	0.33
	^{64m}Sc	—	0.13 ± 0.01	0.15 ± 0.02	0.14 ± 0.05	
Cu	^{52g}Mn	—	—	0.128 ± 0.01	—	0.53
	^{52m}Mn	0.53 ± 0.05	0.47 ± 0.05	0.525 ± 0.05	0.473 ± 0.05	

TABLE II.

Type of target	Photon energy, MeV	Isomeric yield ratio	Remarks
^{51}V	65-300	0.75 ± 0.03	[11] [18] Present work
	100-300	0.88	
	2000-5000	0.87 ± 0.04	
^{54}Fe	250	0.61 ± 0.02	[7] [8]
	250-300	1.03 ± 0.05	
^{55}Mn	225	0.72	[7] [7] [8] Present work
	300	0.64	
	250-300	1.09 ± 0.04	
	2000-5000	1.02 ± 0.02	
^{59}Co	250-300	1.24 ± 0.06	[8] Present work
	2000-5000	1.84 ± 0.16	
^{72}As	250-300	1.9 ± 0.3	[8]
^{54}Fe	70	0.47	[7] [7] Present work
	100-250	0.56	
^{55}Mn	100-300	0.38	[7] Present work
	2000-5000	1.12 ± 0.1	
^{59}Co	150	1.62	[7] Present work
	4000	4.1 ± 0.4	

ELEM. SYM.	A	Z
V	51	23

METHOD	REF. NO.	
	78Di12	hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,SPL	ABY	THR-999	C	300-999	ACT-I		4PI

Abstract—Cross sections per equivalent quantum, in the energy range 0.3–1.0 GeV, have been measured for spallation residuals from ^{51}V , ^{55}Mn , natural Fe, and ^{59}Co targets. Mean cross sections per photon have been deduced in this energy range and the data analysed in terms of charge-dispersion curves and mass-yield distributions. The mean cross sections per photon have also been compared with a semiempirical Rudstam's formula. A satisfactorily good agreement has been found with the calculated yields within a factor of two.

YLDS 24NE TO 49CR

Table 2. Yields of radionuclides in units of μb per equivalent quantum. Vanadium target

Nuclide	$E_0(\text{GeV})$						
	0.30	0.40	0.50	0.60	0.75	0.90	1.00
^{24}Ne	1.4 ± 0.3	2.0 ± 0.4	2.5 ± 0.4	2.6 ± 0.4	3.4 ± 0.4	3.5 ± 0.4	3.8 ± 0.4
^{23}Na	10 ± 3	20 ± 4	25 ± 4	25 ± 4	28 ± 4	32 ± 4	30 ± 4
^{22}Na	2.0 ± 0.4	8.0 ± 1.2	15.0 ± 1.8	20 ± 2	25 ± 2	32 ± 2	34 ± 2
^{24}Mg	3.0 ± 0.6	10 ± 1	15 ± 2	20 ± 2	25 ± 2	28 ± 2	30 ± 2
^{25}Mg	1.5 ± 0.5	2.5 ± 0.8	3.8 ± 0.8	5.0 ± 0.8	6.5 ± 0.9	7.5 ± 0.9	8 ± 1
^{27}Al	12 ± 4	25 ± 5	35 ± 5	50 ± 6	60 ± 7	75 ± 9	80 ± 10
^{26}Al	10 ± 3	17 ± 4	20 ± 5	25 ± 3	34 ± 4	37 ± 4	40 ± 5
$^{36}\text{Cl}^-$	1.0 ± 0.3	5.2 ± 1.3	9.0 ± 1.8	12.0 ± 1.4	15.0 ± 1.8	18 ± 2	20 ± 3
^{35}Cl	40 ± 10	60 ± 9	80 ± 12	90 ± 13	110 ± 13	120 ± 14	130 ± 16
^{37}Cl	15 ± 5	25 ± 7	35 ± 6	40 ± 6	50 ± 6	55 ± 6	60 ± 6
^{40}Ar	20 ± 4	40 ± 6	50 ± 6	65 ± 6	80 ± 8	90 ± 8	100 ± 10
^{41}K	200 ± 30	250 ± 40	350 ± 42	420 ± 50	417 ± 40	500 ± 50	540 ± 55
^{40}K	50 ± 7	83 ± 12	120 ± 18	150 ± 18	176 ± 20	200 ± 30	190 ± 30
^{42}K	35 ± 10	45 ± 14	50 ± 15	60 ± 15	65 ± 15	72 ± 12	75 ± 12
^{43}K	1.0 ± 0.3	4 ± 1	7 ± 2	9 ± 2	11 ± 2	13 ± 3	15 ± 3
^{44}Ca	10 ± 3	13 ± 4	15 ± 5	18 ± 4	19 ± 4	25 ± 5	23 ± 5
^{46}Sc	20 ± 3	44 ± 7	80 ± 10	100 ± 12	107 ± 10	130 ± 10	150 ± 10
$^{45}\text{Sc}^-$	214 ± 20	300 ± 30	350 ± 40	400 ± 40	475 ± 40	500 ± 40	525 ± 40
$^{46}\text{Sc}^+$	250 ± 20	320 ± 30	350 ± 40	410 ± 40	470 ± 40	490 ± 40	530 ± 40
^{47}Sc	714 ± 70	950 ± 76	1000 ± 100	1100 ± 100	1200 ± 100	1400 ± 100	1430 ± 100
^{48}Sc	1100 ± 100	1300 ± 100	1300 ± 100	1400 ± 110	1500 ± 110	1600 ± 100	1700 ± 100
^{49}Sc	120 ± 10	200 ± 16	200 ± 16	250 ± 15	260 ± 15	300 ± 15	346 ± 15
^{51}V	470 ± 40	630 ± 50	630 ± 50	650 ± 50	690 ± 50	740 ± 50	760 ± 50
^{52}Cr	56 ± 10	63 ± 12	65 ± 13	70 ± 10	75 ± 10	77 ± 10	80 ± 10
^{53}Cr	15 ± 3	20 ± 4	23 ± 4	25 ± 5	28 ± 5	30 ± 5	31 ± 5

Table 6. Mean cross sections in the energy range 0.3–1 GeV in units of μb

Produced radio-nuclide	Target nucleus				
	Vanadium		Manganese	Iron	Cobalt
	Present work	Bülow <i>et al.</i> [26]			
^{24}Ne	2.0 ± 0.4				
^{23}Na	16 ± 4				
^{22}Na	30 ± 2	18 ± 2	10 ± 1	10 ± 1	7 ± 1
^{24}Mg	22 ± 2	18 ± 3	9 ± 1	10 ± 1	8 ± 1
^{25}Mg	6 ± 1	6 ± 1	2.7 ± 0.5	2.7 ± 0.5	2.2 ± 0.3
^{27}Al	58 ± 7	59 ± 4	29 ± 4	35 ± 4	25 ± 3
^{26}Al	25 ± 4	32 ± 2	11 ± 2	15 ± 2	16 ± 3
$^{36}\text{Cl}^-$	16 ± 2	14 ± 2	30 ± 4	30 ± 4	19 ± 3
^{35}Cl	75 ± 13	96 ± 5	45 ± 8	50 ± 8	37 ± 7
^{37}Cl	37 ± 7	35 ± 1	12 ± 2	19 ± 3	13 ± 2
^{40}Ar	65 ± 6	54 ± 2	35 ± 4	28 ± 3	12 ± 2
^{41}K	280 ± 50	243 ± 11	94 ± 17	80 ± 15	66 ± 12
^{40}K	128 ± 20	128 ± 4	43 ± 7	30 ± 5	28 ± 5
^{42}K	33 ± 12	30 ± 3	11 ± 4	10 ± 4	9.5 ± 4
^{43}K	12 ± 2	8 ± 1	1.0 ± 0.5	1.2 ± 0.5	1.0 ± 0.5
^{44}Ca	12 ± 4	15 ± 1	6.5 ± 2.4	6 ± 2	2.2 ± 0.8
^{46}Sc	104 ± 10	109 ± 6	72 ± 7	77 ± 8	52 ± 6
$^{45}\text{Sc}^-$	260 ± 30	243 ± 14	115 ± 15	100 ± 12	84 ± 10
$^{46}\text{Sc}^+$	230 ± 40	218 ± 13	116 ± 20	90 ± 16	71 ± 13
^{47}Sc	575 ± 100	605 ± 18	260 ± 45	214 ± 35	220 ± 40
^{48}Sc	457 ± 100	540 ± 33	200 ± 45	160 ± 30	127 ± 30
^{49}Sc	165 ± 15	138 ± 8	50 ± 5	30 ± 3	25 ± 3
^{51}V	210 ± 50	307 ± 12	200 ± 50	184 ± 45	100 ± 25
^{52}Cr	20 ± 10		7 ± 3	8 ± 4	5.0 ± 2.5
^{53}Cr	13 ± 5	16 ± 2	40 ± 15	64 ± 25	20 ± 8
^{54}Cr			480 ± 150	570 ± 150	330 ± 150
^{55}Mn				25 ± 5	
$^{56}\text{Mn}^-$				75 ± 40	49 ± 25
$^{57}\text{Mn}^+$				96 ± 40	84 ± 25
^{58}Mn				944 ± 300	584 ± 100
^{59}Co					1.6 ± 0.8

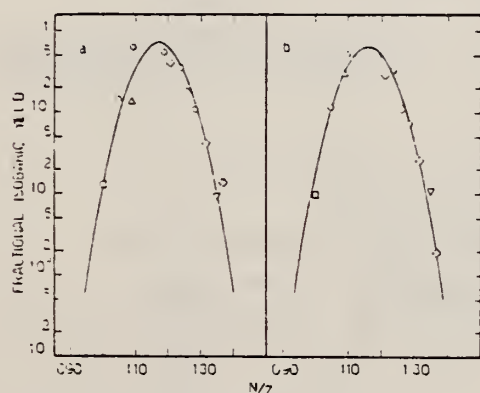


Fig. 1. Fractional isobaric yield vs the N/Z ratio for $42 \leq A \leq 48$. Mean cross sections per photon in the energy range 0.3–1 GeV. Graph (a): ^{51}V target; (b): ^{55}Mn target. The symbols are: \square , for Cr; \circ , for Sc; Δ , for V; \diamond , for K; ∇ , for Ca isotopes.

Table 7. N/Z dispersion parameters of the mean cross sections per photon†

Target nucleus	Mass region	A_m	N/Z_p	Z_p	FWHM	ΔZ	Ref.
^{51}V	42–48	45	1.16	20.8	0.143	1.36	Present work
			1.16	20.8	0.142	1.37	[26]
			1.16	20.9	0.168	1.63	[35]
^{55}Mn	42–48	45	1.16	20.8	0.142	1.37	Present work
^{56}Fe	42–48	45	1.16	20.8	0.140	1.35	Present work
	48–54	51	1.16	23.6	0.126	1.38	Present work
^{59}Co	42–48	45	1.16	20.8	0.141	1.36	Present work
	48–54	51	1.16	23.6	0.124	1.36	Present work

† A_m is the median mass of the mass region under consideration. N/Z_p is the neutron/proton ratio for the most probable nuclear charge Z_p of A_m . FWHM is the full width at half-maximum of the CD curves. ΔZ is the spread in Z as calculated from the FWHM for the two abscissas N/Z_1 and N/Z_2 (see also Refs. [26] and [35]).

ELEM. SYM.	A	Z
V	51	23
REF. NO.		hg
78 Ma 10		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,A	ABY	10-68	C	30-68	ACT - I		4PI
G,AN	ABY	18-68	C	30-68	ACT - I		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

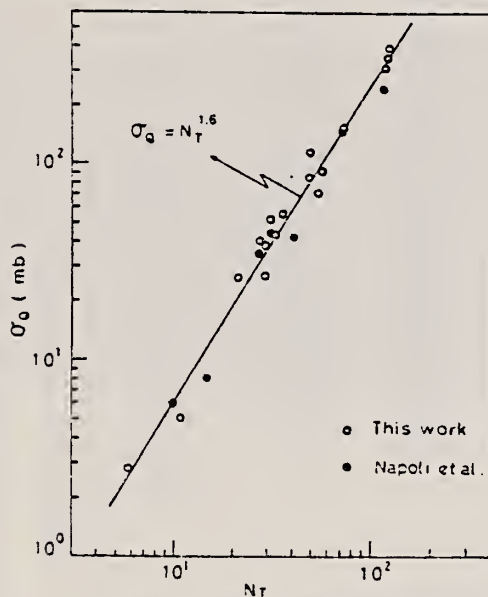


Fig. 2. Yield per equivalent quanta versus target neutron number.

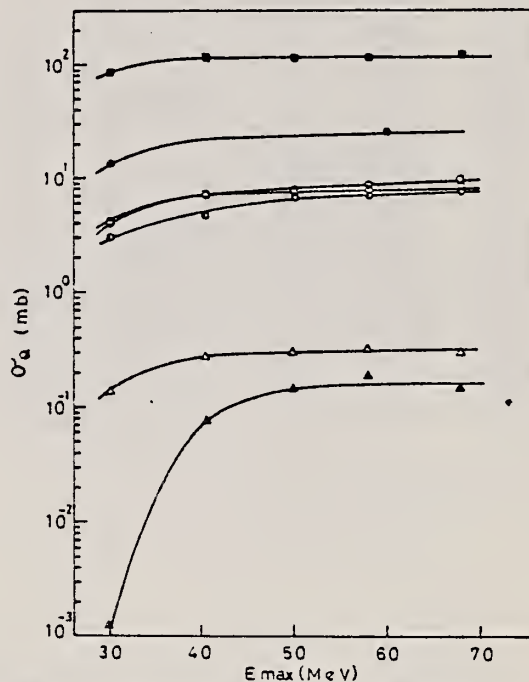


Fig. 4. Activation yield curves for the reactions on Ca, Ti and V.

■ $^{48}\text{Ca}(\gamma, n)^{47}\text{Ca}$, □ $^{44}\text{Ca}(\gamma, p)^{43}\text{K}$, ● $^{46}\text{Ti}(\gamma, n)^{45}\text{Ti}$,
 ○ $^{48}\text{Ti}(\gamma, p)^{47}\text{Sc}$, ● $^{49}\text{Ti}(\gamma, p)^{48}\text{Sc}$, △ $^{51}\text{V}(\gamma, \alpha)^{47}\text{Sc}$,
 ▲ $^{51}\text{V}(\gamma, 2n)^{49}\text{Sc}$.

REF.

H. Tsubota, S. Oikawa, J. Uegaki and T. Tamae
Nucl. Phys. A303, 333 (1978)

ELEM. SYM.	A	Z
V	51	23

METHOD

REF. NO.

78 Ts 1

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,XP	ABX	15- 29	D	15- 29	MAG-D		90

Abstract: The differential cross sections of the $(e, e'p)$ reactions for ^{51}V and ^{59}Co have been measured at 90° over the region of excitation corresponding to the electric giant dipole resonance. The (γ, p) cross sections of these nuclei were deduced from differential cross sections assuming isotropic angular distributions of protons. The results are compared with the (γ, n) cross sections, and are used to obtain strengths of the T_2 and T_1 giant dipole states separately by using the statistical theory. For each nucleus the ratio of the separated strengths and the splitting energy are consistent with those expected by the isospin formalism.

G,XP E1-VIRTUAL PHOT

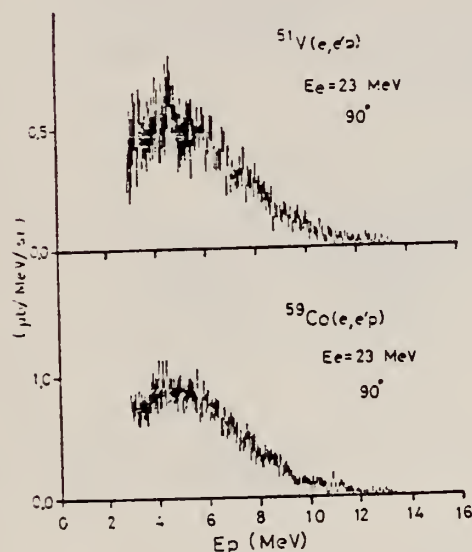


Fig. 2. Typical proton energy spectra of the $(e, e'p)$ reactions of ^{51}V and ^{59}Co nuclei at 23.0 MeV of the incident electron energy.

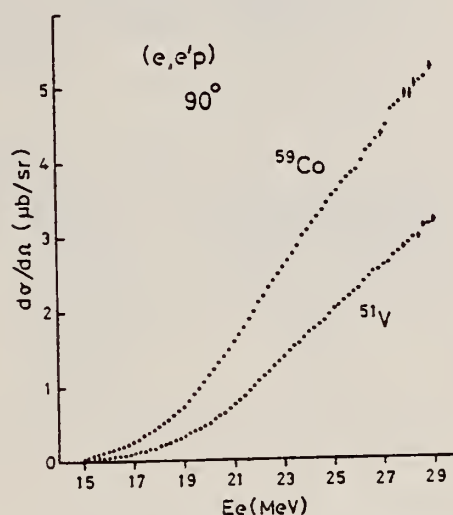


Fig. 3. Proton yield curves of the $(e, e'p)$ reactions of ^{51}V and ^{59}Co nuclei at 90° .

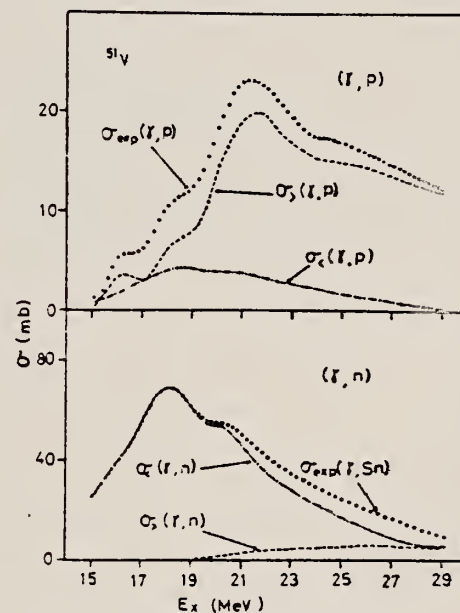


Fig. 8. Comparison between the experimental cross sections and separated isospin components of ^{51}V for (γ, p) and (γ, n) reactions. Notations are explained in the text.

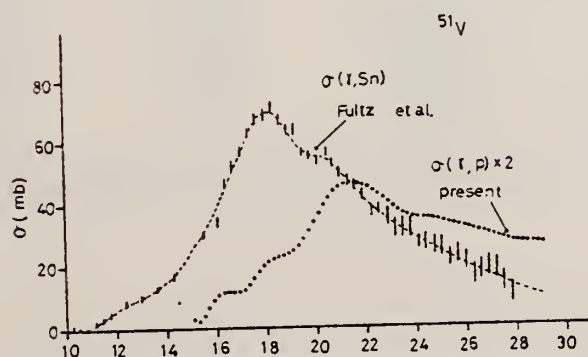


Fig. 5. Comparison between (γ, p) and (γ, Sn) cross sections [$\sigma(\gamma, \text{Sn}) = \sigma(\gamma, n) + \sigma(\gamma, np) + \sigma(\gamma, 2n)$] of ^{51}V . The dashed curve is the (γ, Sn) cross section used in the present analysis.

TABLE 2

Summary of the parameters obtained from the differential cross sections at 90° for ^{51}V and ^{59}Co

	Range of measurement (MeV)	$\int \frac{d\sigma(\gamma, p)}{d\Omega} dE$ (MeV · mb/sr)	$4\pi \int \frac{d\sigma(\gamma, p)}{d\Omega} dE$ (MeV · mb)
^{51}V	15.0–29.0	16.32 ± 1.39	205 ± 17
^{59}Co	15.0–29.0	28.10 ± 2.00	353 ± 25

METHOD					REF. NO.	
					79Ts2	hg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,P0	ABX	14-26	C	15-26	MAG-D	

Abstract: The differential cross sections at 90° for the $^{51}\text{V}(e, p_0)^{50}\text{Ti}$ and $^{52}\text{Cr}(e, p_0 + p_1)^{51}\text{V}$ reactions have been measured over the giant dipole resonance region. These cross sections were used to obtain the differential cross sections of the $^{51}\text{V}(\gamma, p_0)^{50}\text{Ti}$ and $^{52}\text{Cr}(\gamma, p_0 + p_1)^{51}\text{V}$ reactions. The results show two peaks that appear at the same energies as the main peaks of the (γ, n) and (γ, p) cross section for both nuclei. The angular distributions of protons from the (e, p) reaction have also been measured at several points of the incident electron energy. The coefficients A_2 obtained by fitting with a series of Legendre polynomials, $W(\theta) = 1 + A_1 P_1(\cos \theta) + A_2 P_2(\cos \theta)$, varies with excitation energy. These results are discussed in terms of the direct-semidirect process considering isospin effects in the giant dipole resonance.

VIRTUAL PHOTON ANAL.

E NUCLEAR REACTIONS ^{51}V , $^{52}\text{Cr}(e, p_0)$, (γ, p_0) , $E = 15.0\text{--}26.0$ MeV; measured $\sigma(E, \theta)$ at $\theta = 90^\circ$, measured $\sigma(E, \theta)$ at several E -values for ^{51}V and at $E = 21.4$ MeV for ^{52}Cr . Deduced $\sigma(E, \theta)$ for $^{51}\text{V}(\gamma, p_0)$ and for $^{52}\text{Cr}(\gamma, p_0 + p_1)$ at $\theta = 90^\circ$; natural target (^{51}V), enriched target (^{52}Cr).

TABLE 2
Experimental results of the (γ, p_n) reactions

	$\frac{d\sigma(\gamma, p_0)dE}{d\Omega} (90^\circ)$ (MeV · mb sr)	$4\pi \frac{d\sigma(\gamma, p_n)dE}{d\Omega}$ (MeV · mb)	$\frac{d\sigma(\gamma, p)dE}{d\Omega}$ (MeV · mb sr)	$\frac{d\sigma(\gamma, p_n)dE}{d\Omega} \cdot \frac{d\sigma(\gamma, p)dE}{d\Omega}$
^{51}V	0.46 ± 0.07	5.78 ± 0.88	$(15\text{--}29 \text{ MeV})^b$ 16.32	0.03
^{52}Cr	1.70 ± 0.22^a	21.36 ± 2.76^a	$(15\text{--}29 \text{ MeV})^b$ 19	0.09

^a) The $(\gamma, p_0 + p_1)$ cross section.
^b) Ref. ¹). ^c) Ref. ²⁴).

TABLE 3
Coefficients obtained by fitting a series of Legendre polynomials $W(\theta) = 1 + A_1 P_1(\cos \theta) + A_2 P_2(\cos \theta)$

	E_e (MeV)	E_x (MeV)	A_1	A_2
^{51}V	17.0	15.4-16.5	0.21 ± 0.05	0.33 ± 0.09
	18.0	16.4-17.5	0.33 ± 0.04	0.33 ± 0.06
	19.0	17.4-18.5	0.28 ± 0.06	0.25 ± 0.11
	21.0	19.4-20.5	0.21 ± 0.07	0.21 ± 0.13
	22.0	20.4-21.5	0.51 ± 0.08	-0.11 ± 0.13
^{52}Cr	21.4	20.5-21.0	0.06 ± 0.07	0.05 ± 0.11

The range of the excitation energy E_x is also indicated.

(over)

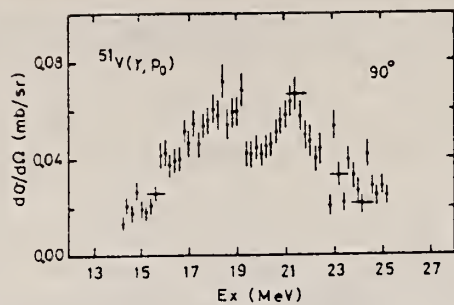


Fig. 2. The differential cross section at 90° for the $^{51}\text{V}(\gamma, p_0)^{50}\text{Ti}$ reaction.

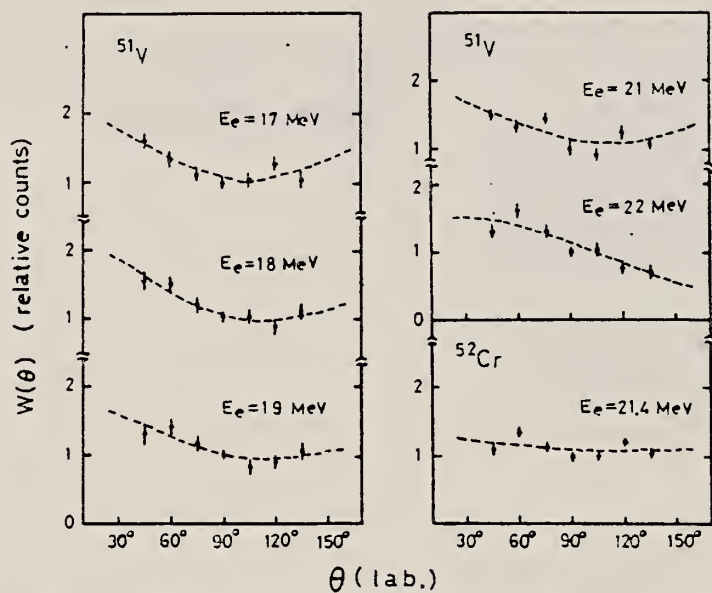


Fig. 6. The angular distributions of protons from the $^{51}\text{V}(e, p_1)^{50}\text{Ti}$ and $^{52}\text{Cr}(e, p_0 + p_1)^{51}\text{V}$ reactions. The dashed curves are the results fitted with the sum of Legendre polynomials, $W(\theta) = 1 + A_1 P_1(\cos \theta) + A_2 P_2(\cos \theta)$.

CHROMIUM

Z=24

L. N. Vauquelin first isolated chromium in 1797 from the mineral crocoite or Sibiran red lead. The name comes from the Greek word "chromos", meaning color, due to the variety of hues in its compounds. The red color of the ruby is caused by the presence of chromic oxide, which distinguishes this costly gem from common crystalline corundum.

CR

Elem. Sym.	A	Z
Cr		24

Method Betatron; neutron yield; threshold detector

Ref. No.
57 Fe 2
NVB

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
Cr(γ, n)	Bremss. 14-30					<p>R = ratio between area of second maximum in cross section and first maximum.</p> <p>R = 0.7 ± 0.14</p> <p>Detector at 90°.</p>

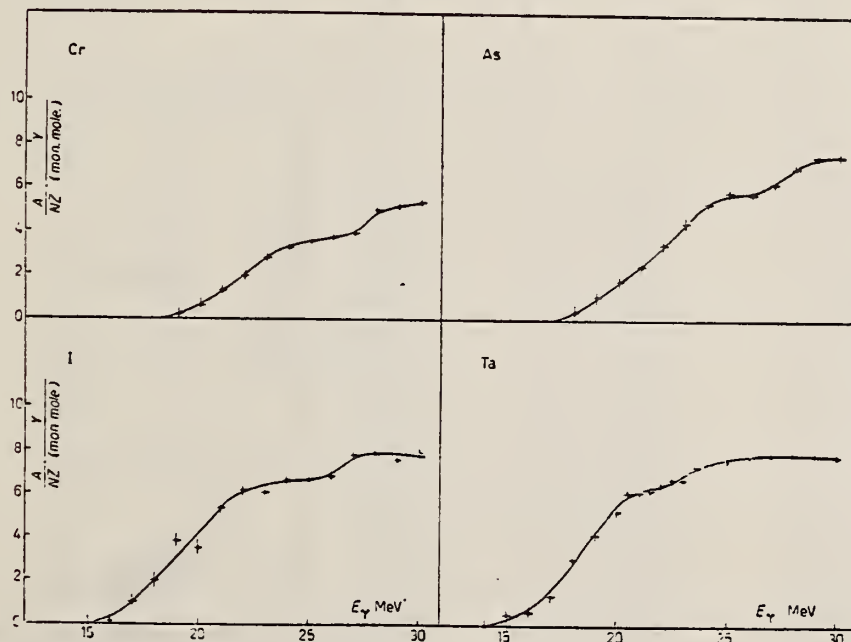


Fig. 1.

Ref. G. Cortini, C. Milone, A. Rubbino, F. Ferrero
Nuovo Cimento 2, 85 (1958)

Elem. Sym.	A	Z
Cr		24
Ref. No.	58 Co 1	
	EH	

Method Emulsions; Betatron; ionization chamber

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
Cr(γ, n)	Bremss					$E_{th} = 11.54 \text{ MeV}$; 90° spectrum. Solid curve from level density formula: $\omega(E_R) = C \exp [2 \sqrt{\alpha E_R}]$; $\alpha = \frac{\pi^2 A}{160}$
	20					
	30					

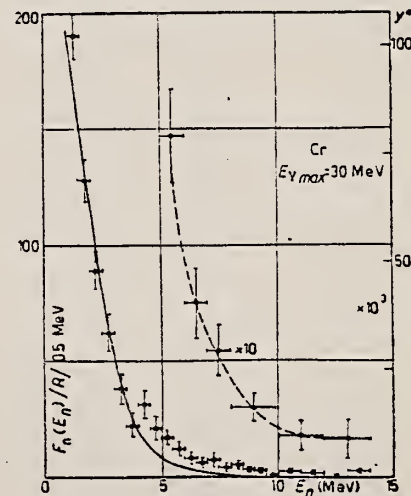
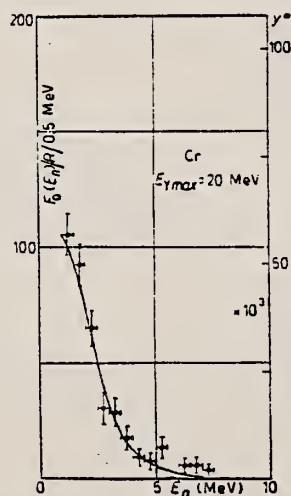


Fig. 2. - Energy spectrum of the photoneutrons from Cr. Experimental figures for the high energy tail are multiplied $\times 10$. The continuous curve is the calculated evaporation spectrum (see text). $Y^* = \text{neutrons } / R / 0.5 \text{ MeV/mole}/\Delta\Omega$.

Ref.

R. Bultel, A.E. Munn
Phys. Rev. 112, 781 (1958)

Elem. Sym.

A

Z

Cr

24

Method

γ 's from $F^{19}(p,\gamma)$ reaction; protons from VanDerGraff; Natl.

Ref. No.

60 Re 1

JHH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(7,7)	$E_\gamma = 7.14 \text{ MeV}$					$\langle \sigma \rangle (E_p = 2.05 \text{ MeV}) = 0.30 \pm .05 \text{ mb}$

METHOD

Betatron; fast neutron yield, angular distribution; Si threshold detector; ion chamber

REF. NO.

61 Ba 2

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XN	ABY	THR-22	C	22	THR-I	5-+	DST

In Table 4:

$\bar{\sigma}$ = average cross section of detector weighted with neutron spectrum

a_0 = neutrons/100 roentgen/mole

$$W(\theta) = a_0 \sum_{n=1}^{\infty} [1 + A_n P_n(\cos \theta)]$$

TABLE IV

I Element	II a_0	III a_1	IV a_2	V $(\bar{\sigma}\Phi) \times 10^{20}$	VI $\Phi_{total}(22 \text{ Mev}) \times 10^9$	VII Φ_{fast}/Φ_{total}
Vanadium	245 (1±0.06)	0.01±0.08	-0.00±0.10	6.05	0.21	0.12
Chromium	164 (1±0.03)	0.04±0.04	-0.05±0.05	4.05	0.17	0.10
Manganese	308 (1±0.02)	0.07±0.03	-0.09±0.04	7.61	0.25	0.12
Iron	200 (1±0.03)	0.05±0.04	-0.17±0.05	4.94	0.18	0.11
Cobalt	390 (1±0.02)	0.08±0.03	-0.22±0.04	9.63	0.26	0.15
Nickel	115 (1±0.05)	0.07±0.07	-0.23±0.09	3.58	0.12	0.12
Copper	347 (1±0.02)	0.05±0.03	-0.29±0.01	8.57	0.30	0.12
Arsenic	482 (1±0.03)	0.11±0.04	-0.24±0.05	11.91	0.33	0.15
Rubidium	638 (1±0.05)	0.13±0.06	-0.14±0.08	15.76		
Strontium	409 (1±0.05)	0.10±0.06	-0.17±0.08	10.10		
Yttrium	290 (1±0.10)	0.08±0.12	-0.12±0.15	7.16		
Silver	590 (1±0.01)	0.10±0.06	-0.22±0.08	14.57	0.87	0.07
Cadmium	905 (1±0.02)	0.02±0.02	-0.26±0.03	22.35		
Iodine	1133 (1±0.03)	0.04±0.04	-0.29±0.05	27.99	1.42	0.08
Barium	1048 (1±0.04)	0.10±0.06	-0.38±0.08	25.89		
Lanthanum	1595 (1±0.02)	0.02±0.03	-0.42±0.04	39.40	1.04	0.15
Cerium	1316 (1±0.05)	0.05±0.06	-0.39±0.08	32.50		
Dysprosium	1652 (1±0.08)	0.04±0.10	-0.34±0.13	40.80		
Tantalum	1558 (1±0.02)	0.01±0.03	-0.22±0.04	38.48	2.50	0.06
Tungsten	1365 (1±0.02)	-0.07±0.03	-0.24±0.01	33.71		
Mercury	1345 (1±0.02)	0.04±0.03	-0.31±0.04	33.22		
Lead	2274 (1±0.01)	0.02±0.02	-0.42±0.03	56.17	2.72	0.08
Bismuth	2162 (1±0.02)	0.05±0.03	-0.45±0.04	53.40	3.36	0.06
Thorium	3031 (1±0.01)	0.06±0.05	-0.32±0.07	71.87		
Uranium	4630 (1±0.02)	0.05±0.03	-0.17±0.04	114.36		

* $(\bar{\sigma}\Phi) = 2.47 \times 10^9$ as millibarn-neutrons. Errors are standard errors due to counting statistics only.

REF.			ELEM. SYM.		A	Z	
F.R. Allum, T.W. Quirk, and B.M. Spicer Nucl. Phys. <u>53</u> , 545 (1964)			Cr			24	
METHOD					REF. NO.		
					64 Al 5		
					JOC		
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	NØX	THR-34	C	34	THR-I	6-	DST

TABLE 1
Summary of present experimental data at 34 MeV bremsstrahlung

Element		$-\frac{a_2}{a_0}$	$\frac{a_1}{a_0}$
^4Be		0.43 ± 0.02	0.05 ± 0.01
^{12}C		0.61 ± 0.04	0.09 ± 0.02
^{13}Al		0.39 ± 0.03	0.05 ± 0.01
^{22}Ti		0.34 ± 0.02	0.06 ± 0.01
^{34}Cr	34 MeV	0.33 ± 0.02	0.02 ± 0.01
	22 MeV	0.13 ± 0.07	-0.02 ± 0.03
^{29}Cu		0.36 ± 0.02	0.10 ± 0.01
^{50}Sn		0.38 ± 0.02	0.11 ± 0.01
^{56}Ba		0.39 ± 0.03	0.11 ± 0.02
^{72}Ta	Before installation of iron shielding	0.26 ± 0.04	0.13 ± 0.02
	After installation of iron shielding	0.27 ± 0.02	0.12 ± 0.01
^{82}Pb	target diameter 3.0 cm	0.39 ± 0.03	0.15 ± 0.02
	target diameter 1.5 cm	0.40 ± 0.03	0.19 ± 0.02
^{83}Bi		0.42 ± 0.03	0.17 ± 0.02

$$Y = a_0 + a_1 \cos \theta + a_2 \cos^2 \theta$$

REF. NO.

Synchrotron; $C^{12}(\gamma, n)$ monitor

64 Co 2

JOC

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
C.XN	ABY	THR - 80	C	80	BF3-I		4 PI

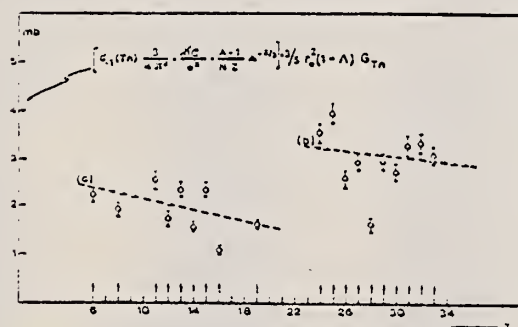
Table 1

Element	Yield ($\frac{30}{60}$) eV cm ² mol MeV	60 NZ/A (mb MeV)	$\frac{30}{\Sigma}$ 0	$\frac{80}{\Sigma}$ 0	$\frac{30}{\Sigma} \frac{80}{\Sigma}$ 0 0	E_m (MeV)	σ_m (mb)
^{24}Cr	83×10^{-5}	777	1.21	2.1	0.58	18.5	97
^{25}Mn	106×10^{-5}	818	1.52	2.33	0.65	18.5	114
^{26}Fe	68×10^{-5}	832	0.88	1.46	0.60	17.5	75
^{27}Co	89×10^{-5}	878	1.08	1.82	0.59	17.5	92
^{28}Ni	44×10^{-5}	879	0.55	1.07	0.51	18.5	56
^{29}Cu	95×10^{-5}	947	1.06	1.99	0.53	17.5	98
^{30}Zn	98×10^{-5}	975	0.94	1.68	0.56	17.5	86
^{31}Ga	130×10^{-5}	1034	1.29	2.18	0.59	17.5	151
^{32}Ge	139×10^{-5}	1064	1.35	2.29	0.59	17.5	158
^{33}As	137×10^{-5}	1109	1.22	2.13	0.56	17.5	127

$$\frac{\frac{30}{\Sigma} \int_0^{30} \sigma(\gamma, xn) dE}{60 \text{ NZ/A}}$$

Table 2

Element	maximum yield ($\times 10^{-5}$)	$\sigma_{-1}(\text{Tn})$	$\sigma_{-1}(\text{Tn}) \times \left[\frac{3}{4\pi^2} \frac{hc}{c^2} \left(\frac{A-1}{NZ} \right) A^{-\frac{1}{2}} \right]$
^6C	4.0	3.54	2.13
^8O	5.2	4.05	1.92
^{11}Na	12.6	11.60	2.49
^{12}Mg	10.0	8.81	1.73
^{13}Al	15.9	13.92	2.30
^{14}Si	11.6	9.96	1.55
^{15}P	19.8	17.56	2.32
^{16}S	9.5	8.55	1.07
^{19}K	19.6	17.90	1.61
^{20}Ca	12.1	11.63	1.02
^{24}Cr	86	61.6	3.56
^{25}Mn	115	76.1	3.96
^{26}Fe	71	50.3	2.55
^{27}Co	94	62.5	2.94
^{28}Ni	46	34.2	1.59
^{29}Cu	102	72.3	2.96
^{30}Zn	93	65.7	2.68
^{31}Ga	140	93.6	3.31
^{32}Ge	150	101.5	3.36
^{33}As	151	99.8	3.12

Fig. 2. Bremsstrahlung weighted cross sections, $\sigma_{-1}(\text{Tn})$, conveniently normalized, versus Z .

REF. J. W. Jury, J. S. Hewitt, and K. G. McNeill Can. J. Phys. <u>46</u> , 1823 (1968)			ELEM. SYM.		A	Z	
			Cr			24	
METHOD			REF. NO.				
			68 Ju 1			EGF	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE .
			TYPE	RANGE	TYPE	RANGE	
G,N	NOX	THR-22	C	22	THR	5-	DST

$$W(\theta) = a_0 + a_1 P_1 + a_2 P_2$$

TABLE I

Target element	Z	Energy	a_0^*	a_1/a_0	a_2/a_0
Vanadium	23	32	640 ± 50	0.11 ± 0.10	-0.09 ± 0.11
Chromium	24	22	365 ± 39	0.02 ± 0.08	0.00 ± 0.10
Manganese	25	22	450 ± 33	0.07 ± 0.05	-0.11 ± 0.06
Bromine	35	27	874 ± 54	0.05 ± 0.06	-0.15 ± 0.08
Molybdenum	42	22	610 ± 60	0.09 ± 0.05	-0.35 ± 0.06
Ruthenium	44	27	1100 ± 25	0.12 ± 0.02	-0.29 ± 0.03
Rhodium	45	27	1270 ± 47	0.06 ± 0.03	-0.14 ± 0.03
Palladium	46	27	1350 ± 29	0.26 ± 0.02	-0.12 ± 0.02
Antimony	51	27	2140 ± 62	0.04 ± 0.08	-0.25 ± 0.11
Lanthanum	57	27	1940 ± 70	0.12 ± 0.10	-0.52 ± 0.14
Praseodymium	59	30	1800 ± 58	0.20 ± 0.08	-0.40 ± 0.09
Platinum	78	27	2600 ± 52	0.17 ± 0.02	-0.15 ± 0.03
Lead	82	22	2274 ± 59	0.08 ± 0.08	-0.46 ± 0.09

*The yield per mole per 100 r was normalized to a yield of 2274 for the lead sample at the same energy.

REF. K. G. McNeill, J. S. Hewitt, and J.W. Jury
Can. J. Phys. 46, 1974 (1968)

ELEM. SYM.	A	Z
Cr		24

METHOD	REF. NO.	
	68 Mc 1	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	SPC	THR-32	C	22-32	THR-I	5-	DST

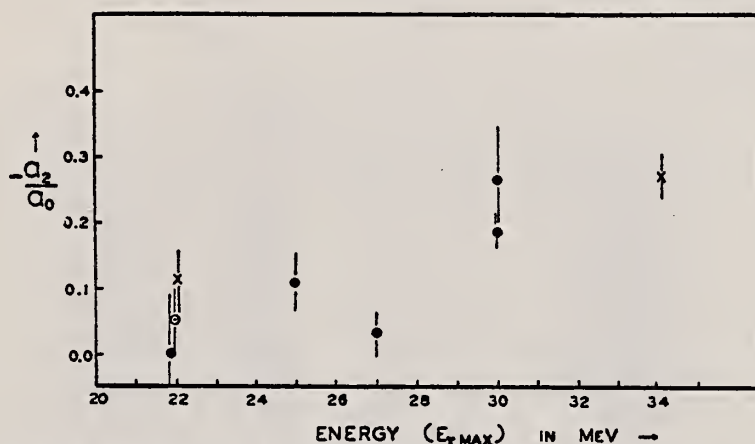


FIG. 2. The variation of anisotropy of fast photoneutrons from chromium with maximum X-ray energy. \odot , present work; \circ , Baker and McNeill (1961); \times , Allum *et al.* (1964).

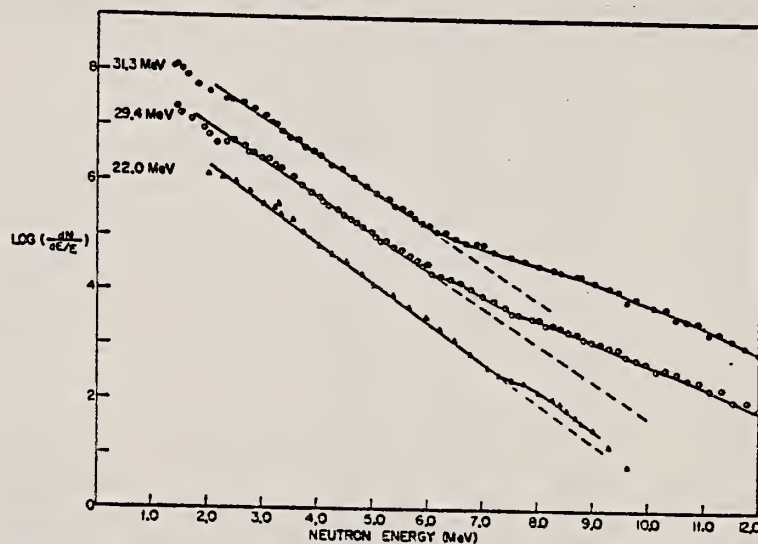


FIG. 3. The energy spectra of neutrons from chromium, measured by neutron time-of-flight techniques with resolution of 0.2 ns/m at three different maximum X-ray energies. The axes are such that a Maxwellian distribution gives a straight line. The experimental errors are approximately the sizes of the plotted points. The ordinate scale for each curve is arbitrary.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	ABX	12-30	C	32	NAI	12-30	DST

GETS G,G/ TO 2+

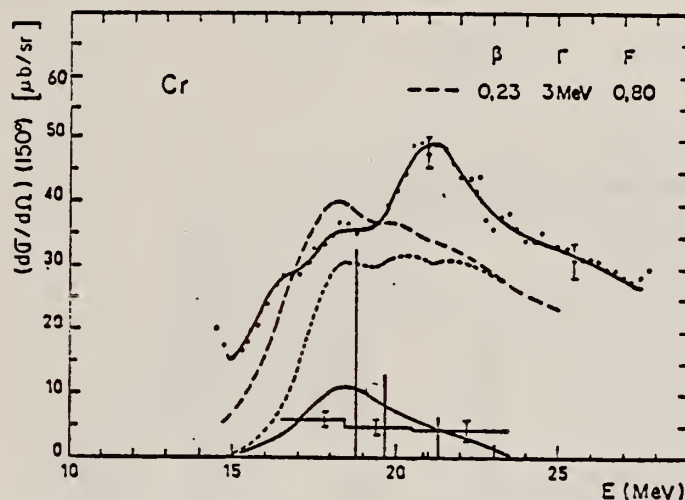


Fig. 6. Differential total scattering cross section at 150° for natural Cr. See caption for fig. 4. The upper dashed curve is the theoretical total scattering cross section and the lower one the theoretical elastic scattering cross section only.

Fig. 4. Differential total scattering cross section at 150° for natural Ti. The full curve through experimental points is only a guide for the eyes. The vertical bars represent the relative strength of dipole levels calculated by the D.C.M. with parameters of table 1. Theoretical elastic plus inelastic scattering is computed from these levels with a common width Γ (dashed curve). Experimental inelastic scattering (histogram) and theoretical inelastic scattering to the first 2⁺ (full curve) are shown in the lower part of the figure. Open circles give the cross section after background subtraction.

TABLE 4
Integrated inelastic scattering cross section

Nucleus	Limits of integration (in MeV)	Experimental ^{a)} $\int \sigma_i(E) dE$ (MeV \cdot μ b)	2 ⁺	Theoretical ^{a)} 2 ⁺ (MeV \cdot μ b)	Total
Ti(⁴⁸ Ti)	16 - 24	250 \pm 50	425	109	534
⁵¹ V(⁵² Cr)	16.4 - 24.9	492 \pm 50	509	116	579
Cr	16.4 - 23.4	431 \pm 60	509	116	579
⁷⁵ As(⁷⁶ Se)	14.1 - 23.6	1254 \pm 120	1373	414	1787
Se(⁸⁰ Se)	14.1 - 24.6	1035 \pm 100	1066	353	1419
⁸⁹ Y					364
Cd(¹¹² Cd)	13.6 - 23.3	3264 \pm 240	1894	370	2264
In(¹¹⁴ Cd)	13.6 - 23.6	2840 \pm 220	2173	388	2561
Sn(¹¹⁰ Sn)	14.2 - 24.2	2363 \pm 220			643

^{a)} We assume an angular distribution of the form $1 + \frac{1}{13} \cos^2 \theta$.

METHOD

REF. NO.

73 Ba 20

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NOX	THR- 27	C	10- 27	BF3-I		4PI

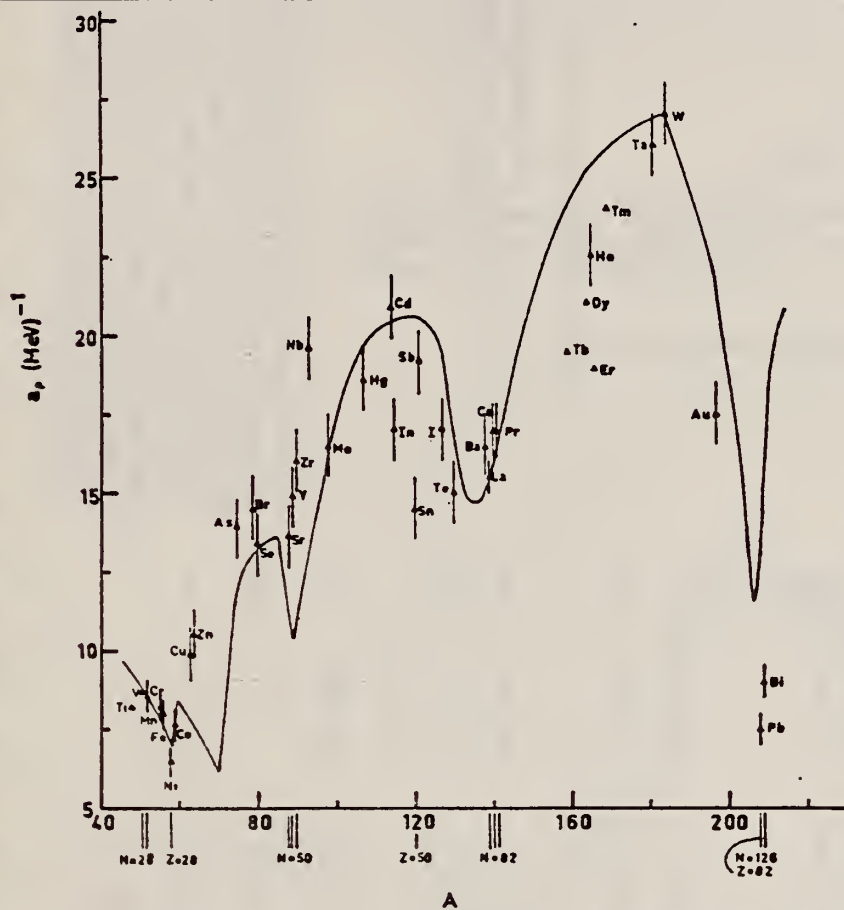


Fig. 12. Experimental values of the level density parameter a_p (Fermi gas formula plus pairing correction) versus atomic number A . The continuous curve is a least-squares fit to the data of a theoretical calculation from Newton ¹⁵.

1

H. Baba and S. Baba, Japan Atomic Energy Research Institute report JAERI-1183 (1969).

2

H. Baba, Nucl. Phys. A159, 625 (1970).

15

T.D. Newton, Can. J. Phys. 34, 804 (1956).

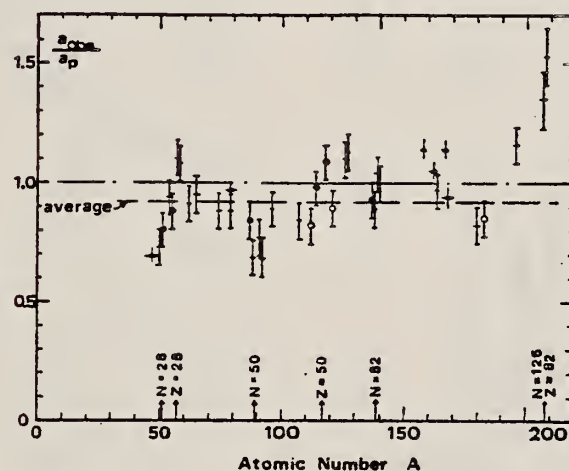


Fig. 15. Ratio a_{obs}/a_p versus atomic number A . Here a_{obs} is the level density parameter taken from the neutron resonance work of refs. ^{1,2}, and a_p is the level density parameter derived from the present (γ, n) work. Filled circles represent points where nuclei in the neutron resonance and in the (γ, n) experiment were the same. Open circles represent points where the respective nuclei were approximately matched. Triangles represent points which are based on measurement of neutron mean energies at two bremsstrahlung energies only.

(over)

TABLE 3

Comparison of experimental and theoretical data on nuclear level densities with Fermi gas formulae, and comparison of nuclear level density parameters from (γ, n) and n-resonance absorption experiments

Target	N (residual nucleus) ^{a)}	Goodness of fit ^{b)}	$E_0(24)$ (MeV) ^{c)}	T (MeV) ^{d)}	a_p (MeV ⁻¹) ^{e)}	a_{obs} (MeV ⁻¹) ^{f)}	a_{obs}/a_p
Ti ^{g)}	23 8% 24 8% 25 73% 26 5% 27 5%		1.93		8.1-47Ti	6.41-47Ti	0.79
V ^{g)}	27 100%		1.96		8.7-50V	6.35-51V	0.73
Cr	25 4% 27 84% 28 10% 29 2%	P G	1.89		8.6-51Cr	6.9-51Cr	0.80
Mn	29 100%	V.P. G	2.1		8.2-54Mn	7.82-56Mn	0.94
Fe	27 6% 29 92% 30 2%	F G	1.96		8.0-55Fe	7.06-55Fe	0.88
Co	31 100%	P F	2.12		7.7-58Co	8.35-58Co	1.08
Ni (Z = 28)	29 68% 31 26% 32 1% 33 4% 35 1%	V.P. P	2.04 1.4		6.5-57.7Ni	7.19-59Ni	1.10
Cu	33 69% 35 31%	V.P. P	1.78 1.0		9.8-62Cu	8.90-64Cu	0.91
Zn	33 49% 35 28% 36 4% 37 19%	F F	1.61		10.5-64.4Zn	10.0-65Zn	0.95
As	41 100%	V.P. F	1.44		14.5-74As	12.81-76As	0.88
Se ^{g)}	41 9% 42 8% 43 24% 45 50% 47 9%		1.39		13.3-78Se	12.8-78Se	0.97
Br	43 45% 45 49%	V.P. V.P.	1.41		14.5-79Br	12.69-80Br	0.88
Sr	47 10% 48 7% 49 83%	F G	1.31		13.6-87Sr	11.4-87Sr	0.84

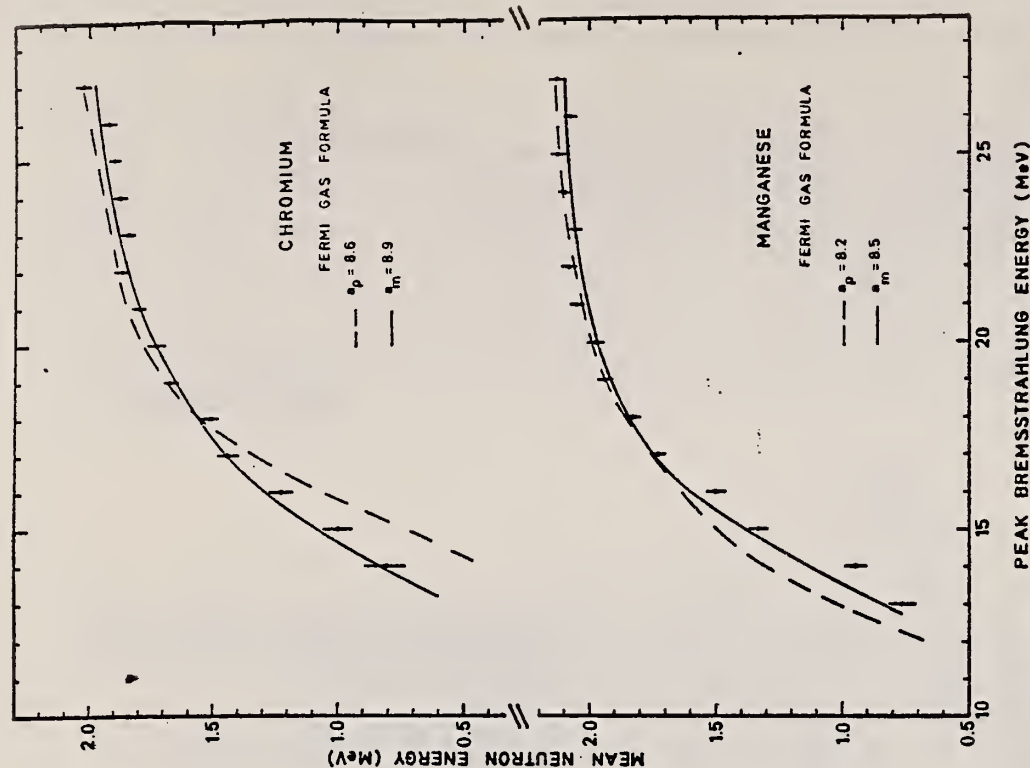


Fig. 5. Variation of photoneutron mean energy with peak bremsstrahlung energy, for chromium and manganese: experimental and calculated results.

^{a)} Neutron numbers and abundances of respective residual nuclei in (γ, n) experiments.

^{b)} These give an assessment of the goodness of fit of a calculated E_n versus E_0 curve to the observed data, using the Fermi gas level density formula both without and with pairing corrections.

^{c)} Bremsstrahlung photoneutron mean energies E_0 for peak bremsstrahlung energy $E_0 = 24$ MeV.

^{d)} Nuclear temperature from fit with constant-temperature formula.

^{e)} Level density parameter a_p derived from the present (γ, n) experiment, using a Fermi gas formula plus pairing correction, and corresponding residual nucleus (the atomic weight shown is the weighted average of atomic weights of the respective isotopes present).

^{f)} As column 7, but using data on n-resonance absorption from refs. 1, 2).

^{g)} Measurements of $E_n(E_0)$ for these nuclei were made only for $E_0 = 21, 23$ and 24 MeV.

ELEM. SYM.	A	Z
Cr		24
REF. NO.		egf
77 We 2		

METHOD						REF. NO.	
						77 We 2	egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	12- 26	C	8- 27	BF3-I		4PI

Abstract

A high resolution measurement of the total photoneutron cross section of chromium from threshold to 27 MeV has been obtained. The result is compared with an earlier measurement and an interpretation in terms of isospin effects is made.

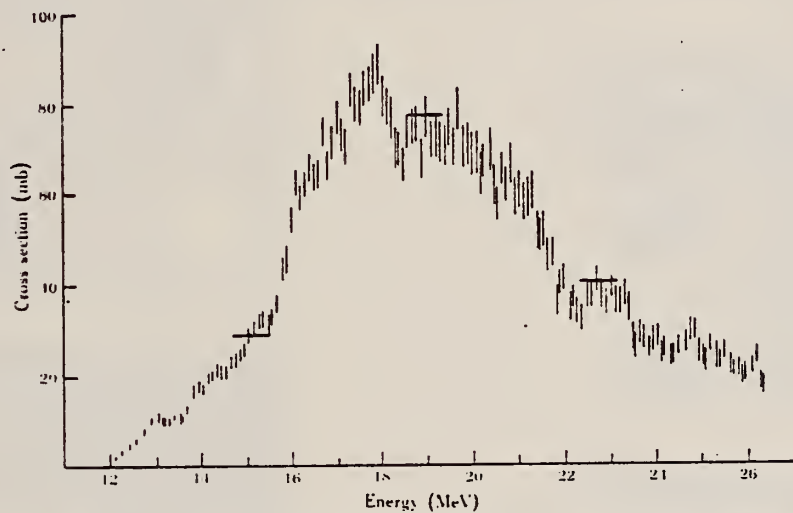


Fig. 1. Photoneutron cross section for natural chromium. The bold horizontal bars represent the analysis bin widths used.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	ABX	14 - 31	C	13 - 31	NAI-D		90

Natural isotopic composition target

B. S. Ishkhanov, Yu. A. Novikov, E. S. Omarov, and I. M. Piskarev

Institute of Nuclear Physics, Moscow State University
(Submitted 21 February 1980)
Yad. Fiz. 32, 1465-1475 (December 1980)

The energy spectra of photons scattered at 90° by ²⁸Si and ⁵²Cr targets have been measured in the betatron bremsstrahlung beam at 16 values of the maximum bremsstrahlung energy from 13.1 to 31 MeV. The photon elastic scattering cross sections in the vicinity of the giant resonance, as well as the cross sections for photon inelastic scattering with excitation of the 1.75 and 4.98 MeV levels of ²⁸Si and the 1.43 and 2.98 MeV levels of ⁵²Cr, were calculated from the spectra. A dispersion-theory analysis of the results enabled us to identify the peaks in the cross sections for which E1 photoabsorption is dominant. The experimental data are compared with the results of shell-model and simple-rotator-model calculations. The nature of the peaks observed in the scattering cross sections is discussed.

PACS numbers: 25.20. + y, 27.30. + t, 27.40. + z

TABLE I. Integrated characteristics of scattering process for ²⁸Si and ⁵²Cr targets.

Target nucleus	Process	Integrated cross section (MeV · mb) out to 32 MeV	
		The present work	Other studies
²⁸ Si, mass, 159 g	Elastic scattering	2.2±0.4	2.3±0.4 [2] 2.0±0.5 [1]
	NRE (1.78 MeV, J ^π = 2 ⁺)	0.8±0.3	Not observed [1]
	Inelastic scattering to the 4.98 MeV 0 ⁺ level	0.7±0.4	—
	Inelastic scattering to the 15.3 MeV 2 ⁺ level	0.24±0.02	—
⁵² Cr, mass, 150 g	Elastic scattering	6.0±0.5	5.5±0.5 [2] 3.8±0.7 [1] 0.6±0.2 [3]
	NRE (1.43 MeV, J ^π = 2 ⁺)	3.0±0.5	—
	Inelastic scattering to the 2.96 MeV 2 ⁺ level	1.2±0.5	—
	Inelastic scattering to the 2.96 MeV 2 ⁺ level	1.2±0.5	—

²H. Arenhövel and J. M. Maison, Nucl. Phys. A147, 305 (1970).

¹B. S. Ishkhanov *et al.*, Yad. Fiz. 30, 1177 (1979) [Sov. J. Nucl. Phys. 30, 610 (1979)].

TABLE III. Characteristics of levels observed in photon scattering from ⁵²Cr.

Total absorption [14-15]		Elastic scattering (the present work)		Inelastic scattering to the indicated levels of ⁵² Cr (the present work)				$\frac{\sigma_{\text{tot}}}{\sigma_{\text{el}}}$, b	$\Delta\pi\%$, b
				1.43 MeV (NRE)		2.96 MeV			
E_{γ} , MeV	σ , mb	E_{γ} , MeV	σ , mb	E_{γ} , MeV	σ , mb	E_{γ} , MeV	σ , mb		
17.5	70	17.2±0.5	380±30	17.0±0.5	350±40			13±3	24.5
20.5	90	20.0±0.5	430±50	20.0±0.5	340±40	20.2±0.5	240±30	19±4	18.4
24.5	20	24.2±0.5	210±20	24.0±0.5	240±40	23.5±0.5	240±30	2±0.5	12.0
28.0*	—	28.0±0.5	200±20	27.0±0.5	120±20	28.0±0.5	120±20		

*Observed in the (γ, n) cross section.²¹

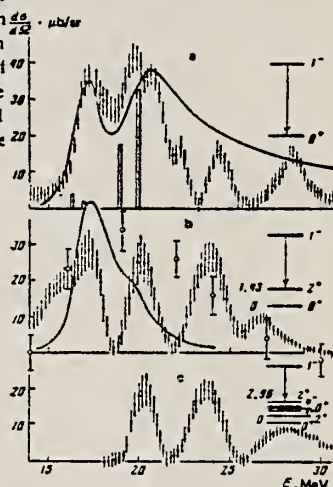


FIG. 4. a) Photon elastic scattering differential cross section for ⁵²Cr. The full curve was calculated using the simple rotator model. The vertical bars were calculated using the theory of finite Fermi systems.¹³ b) Differential cross section for the nuclear Raman effect obtained in the present work (black points) and in Ref. 4 (open circles). The full curve was calculated using the simple rotator model. c) Photon inelastic scattering differential cross section for excitation of the 2.96 MeV J^π = 2⁺ level.

C_R
 $A=50$

C_R
 $A=50$

C_R
 $A=50$

Elem. Sym.	A	Z
Cr	50	24

Ref. No.	
62 De 1	JHH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(γ, n)	20.48					$\sigma(\gamma, n) = 29.1 \pm 6.0 \text{ mb}$

ELEM. SYM.	A	Z
Cr	50	24
REF. NO.		
70 Mo 2		hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	ABX	9	D	9	SCD-D		DST
		(8.888)		(8.888)			

9 = 8.888, LFT

TABLE III. Summary of the results of spins, parities, and total widths of resonance levels excited by γ rays obtained from neutron capture in iron. Parities in parentheses are uncertain.

Isotope	Energy (MeV)	$\delta = |E_r - E_s|$ (eV)	J^π_0	J^π_r	Transition	Γ_0/Γ_γ ($\pm 8\%$)	Γ_γ (10^{-3} eV)
^{50}Cr	8.888	18 ± 1	0^+	1	...	0.90	750 ± 200
^{62}Ni	7.646	14 ± 1	0^+	1^-	E1	0.64	480 ± 50
^{74}Ge	6.018	4.5 ± 0.5	0^+	1^-	E1	0.19	120 ± 15
^{75}As	7.646	7.4 ± 0.3	$3/2^-$	$1/2^+ \rightarrow$	...	0.11	360 ± 100
^{103}Ag	7.632	9 ± 1	$1/2^-$	$3/2$	...	0.7	2 ± 1
^{112}Cd	7.632	4.8 ± 0.4	0^+	1^-	E1	0.55	86 ± 15
^{133}La	6.018	8.2 ± 0.6	$7/2^+$	$7/2^-$	E1	0.50	51^{+14}_{-8}
^{141}Pr	7.632	$11.4^{+0.3}_{-0.8}$	$5/2^+$	$5/2^+$	M1	0.46	72^{+24}_{-3}
^{205}Tl	7.646	9.3 ± 0.3	$1/2^+$	$1/2^- \rightarrow$	...	0.58	930 ± 90
^{208}Pb	7.279	7.1 ± 0.3	0^+	1^+	M1	1.00	780 ± 60

TABLE IV. Effective elastic scattering cross section $\langle \sigma_r \rangle = \sigma_0^r (\Gamma_0/\Gamma_\gamma) \Psi(x_0, t_0)$, where δ , J , Γ_0 , Γ_γ were taken from Table III. The temperature of the scatterer was 300°K, while that of the iron γ source was 640°K.

Target	Resonance energy (MeV)	$\langle \sigma_r \rangle$ (mb)
^{50}Cr	8.888	905
^{62}Ni	7.646	569
^{74}Ge	6.018	61
^{75}As	7.646	4.4
^{103}Ag	7.632	3.5
^{112}Cd	7.632	193
^{133}La	6.018	39
^{141}Pr	7.632	20
^{205}Tl	7.646	574
^{208}Pb	7.279	5560

REF. W. Del Bianco, S. Kundu and P. Boucher
Nucl. Phys. A209, 181 (1973)

ELEM. SYM.	A	Z
Cr	50	24
REF. NO.		
73 De 5		egf

METHOD				REF. NO.		
				73 De 5		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,N	ABX	20- 23	D	20- 23	ACT-I	

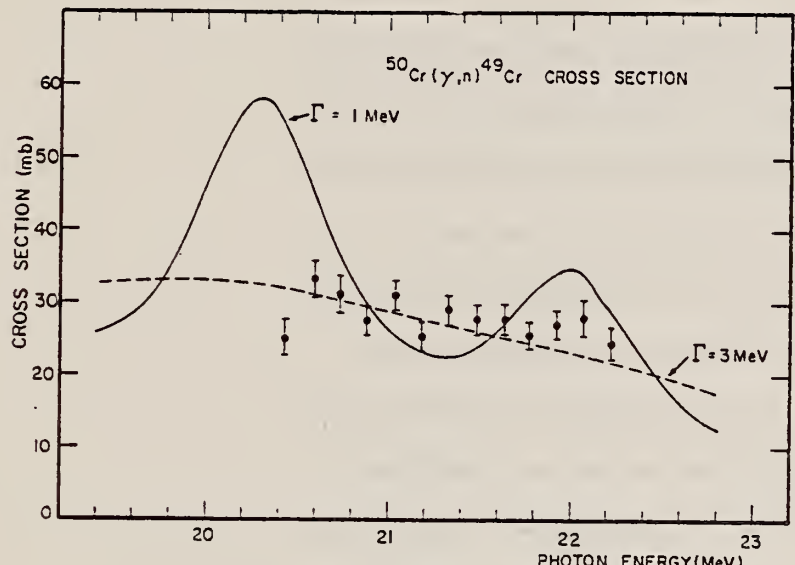


Fig. 4. The $^{50}\text{Cr}(\gamma, n)^{49}\text{Cr}$ cross section. The points are the results of this experiment. The curves represent the normalized theoretical absorption cross section of ref. ²): the solid curve corresponds to $\Gamma = 1$ MeV and the dashed curve to $\Gamma = 3$ MeV, the other parameters being the same as in fig. 1.

² M.G. Huber, M. Danos, H.J. Weber and W. Greiner, Phys.Rev. 155, 1073 (1967).

TABLE 1
Total cross section of the $^{50}\text{Cr}(\gamma, n)^{49}\text{Cr}$ reaction

E_γ (MeV)	σ (mb)
20.43	25.2 ± 2.5
20.58	33.4 ± 2.6
20.73	31.3 ± 2.3
20.88	27.6 ± 2.0
21.03	30.9 ± 2.0
21.18	25.3 ± 1.8
21.33	29.0 ± 1.9
21.48	27.7 ± 1.7
21.63	27.9 ± 1.7
21.78	25.6 ± 1.6
21.92	27.1 ± 1.6
22.07	27.8 ± 2.6
22.22	24.6 ± 2.1

[†] New England Nuclear Corporation, Boston, USA.

REF.	W. Del Bianco, S. Kundu, and P. Boucher PICNS-73, Vol.I, p.557 Asilomar					ELEM. SYM.	A	Z
						Cr	50	24
METHOD						REF. NO. 73 De 8		hmg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE	
			TYPE	RANGE	TYPE	RANGE		
G,N	ABX	20- 22	D	20 -22	ACT-I		4PI	

The measurement of (γ, n) cross sections in spherical medium weight nuclei is of great interest for determining the coupling of low energy surface vibrations and high energy dipole oscillations. The coupling has been theoretically investigated by Huber et al.¹⁾ and found to result in a considerable splitting of the photonuclear resonance. Experimentally bremsstrahlung measurements have indicated a pronounced structure in (γ, n) cross sections^{2, 3)} which is not present in measurements with γ -rays from positron annihilation in flight^{4, 5)}. In this experiment a photoactivation method and monochromatic γ -rays from the $^3\text{H}(p, \gamma)^4\text{He}$ reaction were employed to measure the (γ, n) cross section for ^{50}Cr and ^{64}Zn . The γ -rays were monitored by a NaI(Tl) crystal enclosed in a lead and paraffin shield to reduce background radiation. The positron activity was determined by a coincidence detector consisting of two NaI(Tl) crystals set on the annihilation radiation photopeaks. The γ -ray energy was varied in steps of 150 keV from 20.43 to ≈ 22.2 MeV and the energy resolution was less than 110 keV over the entire energy range. The experimental cross sections of the two reactions were found to vary smoothly as a function of energy. The results for the $^{64}\text{Zn}(\gamma, n)$ process do not agree with those of Owen et al.²⁾, who observed two resonances ≈ 0.5 to 1 MeV wide in the same energy range. The shape of the $^{50}\text{Cr}(\gamma, n)$ cross section is in fair agreement with the calculation of Huber et al.¹⁾ for widths of the dipole states of the order of 3 MeV.

(over)

- 1) M.G. Huber, M. Danos, H. Weber and W. Greiner, Phys. Rev. 155, 1073(1967).
- 2) D.G. Owen, E.G. Muirhead and B.M. Spicer, Nucl. Phys. A122, 177(1968).
- 3) P.H. Cannington, R.J. Stewart and B.M. Spicer, Nucl. Phys. A109, 385(1968).
- 4) R.L. Bramblett, J.T. Caldwell, B.L. Berman, R.R. Harvey and S.C. Fultz,
Phys. Rev. 148, 1198 (1966).
- 5) R.E. Sund, V.V. Verbink, H. Weber and L.A. Kull, Phys. Rev. C2, 1129 (1970).

ELEM. SYM.	A	Z
Cr	50	24
REF. NO.		hg
78 Ma 10		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,PN	ABY	23-68	C	30-68	ACT - I		4PI
G,2N	ABY	24-68	C	30-68	ACT - I		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

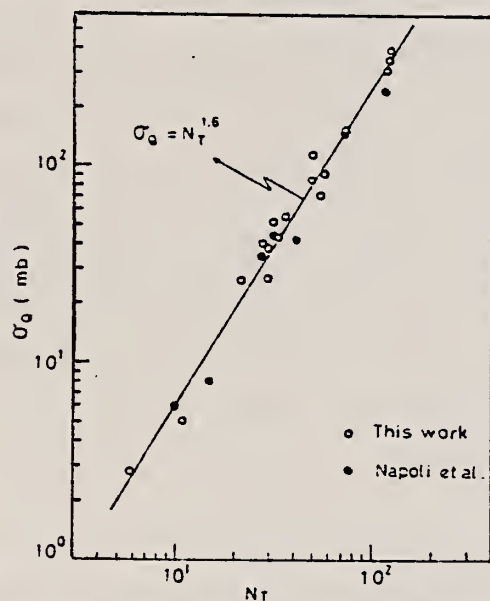


Fig. 2. Yield per equivalent quanta versus target neutron number.

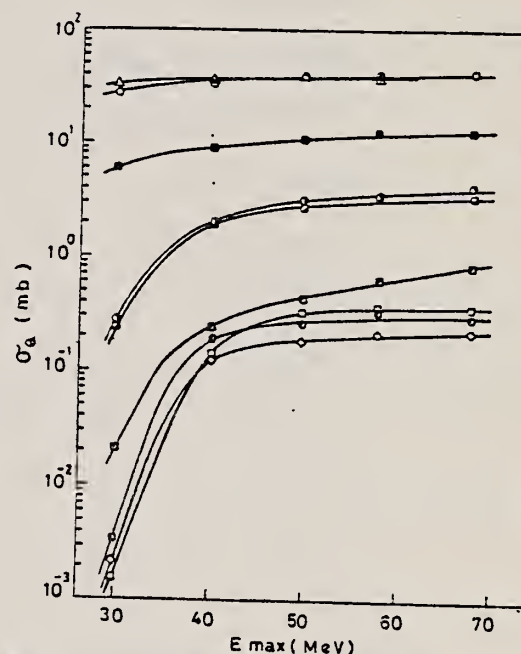


Fig. 5. Activation yield curves for the reactions on Cr, Mn and Fe.

○ $^{52}\text{Cr}(\gamma, n)^{51}\text{Cr}$, ● $^{50}\text{Cr}(\gamma, pn)^{48}\text{V}$, ◐ $^{50}\text{Cr}(\gamma, 2n)^{48}\text{Cr}$,
△ $^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$, ■ $^{57}\text{Fe}(\gamma, p)^{56}\text{Mn}$, ▨ $^{54}\text{Fe}(\gamma, pn)^{52}\text{Mn}$,
▩ $^{56}\text{Fe}(\gamma, pn)^{54}\text{Mn}$, □ $^{56}\text{Fe}(\gamma, xn)^{51}\text{Cr}$, ◇ $^{54}\text{Fe}(\gamma, 2n)^{52}\text{Fe}$.

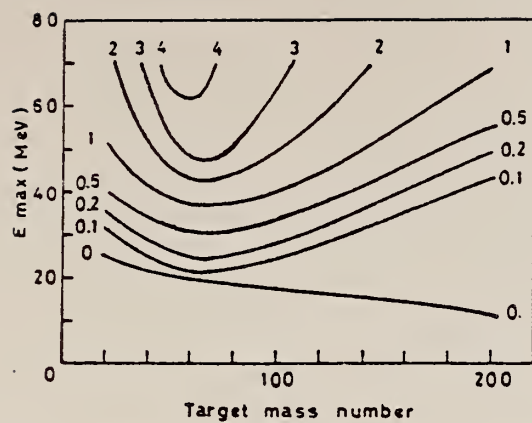


Fig. 11. Yields of the (γ, pn) reactions as a function of bremsstrahlung maximum energy and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

CR
A=52

CR
A=52

CR
A=52

ELEM. SYM. A		
Cr	52	24
REF. NO.	60 Ge 3	NVB

METHOD

Betatron; neutron threshold; ion chamber

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NØX	THR	C THR		BF3-I		4 PI

THRESHOLD

TABLE I. Summary and comparison of neutron separation energies inferred from present threshold measurements with values predicted from mass data and reaction energies. All energies are expressed in the center-of-mass system in Mev.

Reaction	No. runs	Present results	Other results	Method	Reference
$\text{Cr}^{52}(\gamma,n)\text{Cr}^{51}$	1	$\leq 12.18 \pm 0.14$	12.053 ± 0.004	mass data	g

* C. F. Giese and J. L. Benson, Phys. Rev. 110, 712 (1958).

TABLE II. Comparison of measured threshold energies with neutron binding energies predicted by mass data for transitions with $\Delta I \geq 7/2$. All energies in Mev.

Reaction	ΔI^a	Observed threshold	Mass data Q value	$E_{th}-Q$	Excited state energy
$\text{Cr}^{52}(\gamma,n)\text{Cr}^{51}$	7/2	12.18 ± 0.14	12.053 ± 0.004^b	0.13 ± 0.14	...
$\text{Y}^{88}(\gamma,n)\text{Y}^{87}$	7/2	11.59 ± 0.08	11.53 ± 0.40^c	0.06 ± 0.41	0.387^d
$\text{In}^{115}(\gamma,n)\text{In}^{114}$	7/2	9.22 ± 0.03	9.35 ± 0.43^e	-0.13 ± 0.43	0.191^e
$\text{Ce}^{143}(\gamma,n)\text{Ce}^{142}$	(7/2)*	7.24 ± 0.07	6.97 ± 0.07^f	0.27 ± 0.10	...
$\text{Nd}^{146}(\gamma,n)\text{Nd}^{145}$	7/2	6.38 ± 0.16	5.97 ± 0.19^f	0.41 ± 0.25	0.690^g
$\text{Sm}^{149}(\gamma,n)\text{Sm}^{148}$	7/2	6.45 ± 0.16	5.87 ± 0.28^f	0.58 ± 0.33	0.562^g
$\text{Er}^{167}(\gamma,n)\text{Er}^{166}$	7/2	6.65 ± 0.08	6.45 ± 0.06^g	0.20 ± 0.10	0.081^g
$\text{Hf}^{177}(\gamma,n)\text{Hf}^{176}$	7/2	6.69 ± 0.03	6.28 ± 0.06^g	0.64 ± 0.07	0.088^g
$\text{Hf}^{179}(\gamma,n)\text{Hf}^{178}$	9/2	6.31 ± 0.07	6.17 ± 0.06^g	0.14 ± 0.09	0.093^g
$\text{Hf}^{180}(\gamma,n)\text{Hf}^{179}$	9/2	7.85 ± 0.11	7.32 ± 0.06^g	0.53 ± 0.13	0.375^g

* D. Strominger, J. M. Hollander, and G. T. Seaborg, Revs. Modern Phys. 30, 585 (1958).

* C. F. Giese and J. L. Benson, Phys. Rev. 110, 712 (1958).

* Henry E. Duckworth, Mass Spectroscopy (Cambridge University Press, New York, 1958), p. 177.

* S. Dzalepov and L. K. Peker, Atomic Energy of Canada Limited Report Tr. AECL-437 (unpublished).

* The discrepancy in the case of Ce^{143} predicts a ground-state spin for Ce^{142} of 0, since the spin of Ce^{143} is known to be 7/2.

* W. H. Johnson, Jr., and A. O. Nier, Phys. Rev. 105, 1014 (1957).

* W. H. Johnson, Jr., and V. B. Bhanot, Phys. Rev. 107, 6 (1957).

REF.	J. Bellicard and P. Barreau and D. Blum Nucl. Phys. <u>60</u> , 319-336 (1964)	ELEM. SYM.	A	Z
		Cr	52	24
METHOD	Linac; Faraday cup/SEM monitor	REF. NO.	64 Be 3	JOC

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	0 - 9	D	150, 180	MAG-D		DST

TABLE 1

Values of the fitting parameters β_L with the Born approximation inelastic form factors for transitions of angular momentum change L .

J-PI

ϵ (MeV)	$J\pi$	β	Γ (eV)	$B \frac{(L \rightarrow 0)}{e^2}$	$B^{sp}(L \rightarrow 0)$ e^2	G
1.43	2+	0.0390	0.50×10^{-3}	103 fm ⁴	11.1 fm ⁴	9.25
		30	4	8		75
2.37	4+	0.0177	2.00×10^{-12}	7500 fm ⁸	2200 fm ⁸	3.4
		30	34	1300		6
2.97	4+	0.0132	11.2×10^{-12}	5580 fm ⁸	2200 fm ⁸	2.52
		18	1.5	760		35

Values of the reduced transition probabilities $B_{exp}(L \rightarrow 0)$ are compared with the single-particle estimate of Moszkowski ²²⁾ $B_{sp}(L \rightarrow 0)$. Their ratio $G = B_{exp}(L \rightarrow 0)/B_{sp}(L \rightarrow 0)$ is also indicated. Values of γ -ray widths $\Gamma_{exp}(L \rightarrow 0)$ are calculated from the corresponding value of $B_{exp}(L \rightarrow 0)$.

TABLE 2

Values of the fitting parameters β_{exp} with the Born approximation inelastic form factors given by Walecka theory for one and two-surfon quadrupole transitions are compared with the theoretical estimates β_{th} given in this theory.

ϵ (MeV)	Transition	β_{th} ($\times 10^3$)	β_{exp} ($\times 10^3$)
1.43	$0+ \frac{2}{2} 2+$	3.9	3.9
2.65	$0+ \frac{2^2}{2} 0+$	0.0168	0.05
3.16	$0+ \frac{2^2}{2} 2+$	0.385	2.9

TABLE 3

Values of the fitting parameters β_3 with the Born approximation inelastic form factors for transitions of angular momentum change 3

ϵ (MeV)	$J\pi$	β	Γ (eV)	$B(L \rightarrow 0)$ e^2	$B_{sp}(L \rightarrow 0)$ e^2	G
4.60	3-	0.0290	15.6×10^{-6}	932 fm ⁶	152 fm ⁶	6.1
		15		48		3
5.50	3-	0.0053	10.7×10^{-6}	186 fm ⁶		1.2
		12		40		24
6.60	3-	0.0096	65.2×10^{-6}	316 fm ⁶		2.00
		12		40		24
7.10	3-	0.0120	138×10^{-6}	400 fm ⁶		2.40
		12		40		24
7.90	3-	0.0120	292×10^{-6}	400 fm ⁶		2.40
		12		40		24
8.60	3-	0.0096	422×10^{-6}	316 fm ⁶		2.00
		12		40		24

Values of the reduced transition probabilities $B_{exp}(3 \rightarrow 0)$ compared with the single-particle estimate of Moszkowski ²²⁾ $B_{sp}(3 \rightarrow 0)$. Their ratio $G = B_{exp}(3 \rightarrow 0)/B_{sp}(3 \rightarrow 0)$ is also indicated. Values of γ -ray widths $\Gamma_{exp}(3 \rightarrow 0)$ are calculated from the corresponding values of $B_{exp}(3 \rightarrow 0)$.

REF. E. C. Booth, B. Chasan and K. A. Wright
Nuc1. Phys. 57, 403-420 (1964)

ELEM. SYM.	A	Z
Cr	52	24

METHOD					REF. NO.	
Van de Graaff; resonance fluorescence					64 Bo 1	NVB
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,G	LFT	1-3	C	1 - 3	NAI-D	100
		(0.5 - 3.0)		(0.5 - 3.0)		

ABI

TABLE I
Cases of observed resonance fluorescence

Nucleus multipol.	State (MeV)	Spin	Γ_0/Γ	$T(gw\Gamma_0^2/\Gamma^2)^{-1}$ (sec).	Mean lifetime T BCW (sec)	Mean lifetime T other (sec)	Ref.	Γ_0/Γ_w BCW
Cr ⁵²	0.00	0 ⁺						
E2 ^a)	1.43	2 ⁺	1	$3.4 \pm 1 \times 10^{-12}$	$11 \pm 3 \times 10^{-12}$	$10.2 \pm 1.3 \times 10^{-12}$	c)	15

REF. S. Costa, F. Ferrero, S. Ferroni and R. Malvano Proc. Paris Conference 1034 (1964)			ELEM. SYM.	A	Z
			Cr	52	24
METHOD 100 MeV synchrotron			REF. NO. 64 Co 3		JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	AB I	THR-80	C	10-80	BF3-I		4PI

TABLE

ELEMENT	Yield (36 MeV) $\left(\frac{\text{n. cm}^2}{\text{mol. MeV}}\right) \times 10^5$	Σ_0^{30}	Σ_0^{80}	$\Sigma_0^{30} / \Sigma_0^{80}$	σ_{-1} (mb)
²⁴ Cr	83	1.21	2.1	0.58	62
²⁵ Mn	108	1.52	2.33	0.65	76
²⁶ Fe	68	0.88	1.46	0.60	50
²⁷ Co	89	1.08	1.82	0.59	64
²⁸ Ni	44	0.55	1.07	0.51	34
²⁹ Cu	95	1.06	1.99	0.53	72
³⁰ Zn	88	0.94	1.68	0.56	66
³¹ Ga	130	1.29	2.18	0.59	94
³² Ge	139	1.35	2.29	0.59	101
³³ As	137	1.22	2.18	0.56	100

$\Sigma_0^b = \frac{A}{60 NZ} \int_0^b \sigma(E) dE$ is the integrated cross section measured in units of the classical dipole $60 NZ/A$ mb. MeV.

REF. B.I. Goryachev, B.S. Ishkhanov, I.M. Kapitonov, I.M. Piskarev,
V.G. Shevchenko & O.P. Shevchenko
Izv. Akad. Nauk. Fiz. 33, 1736 (1969)
Bull. Acad. Sci. USSR-Phys. 33, 1588 (1969)

ELEM. SYM.	A	Z
Cr	52	24

METHOD

REF. NO.

69 Go 3

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	12-30	C	12-30	BF3-I		4PI

449

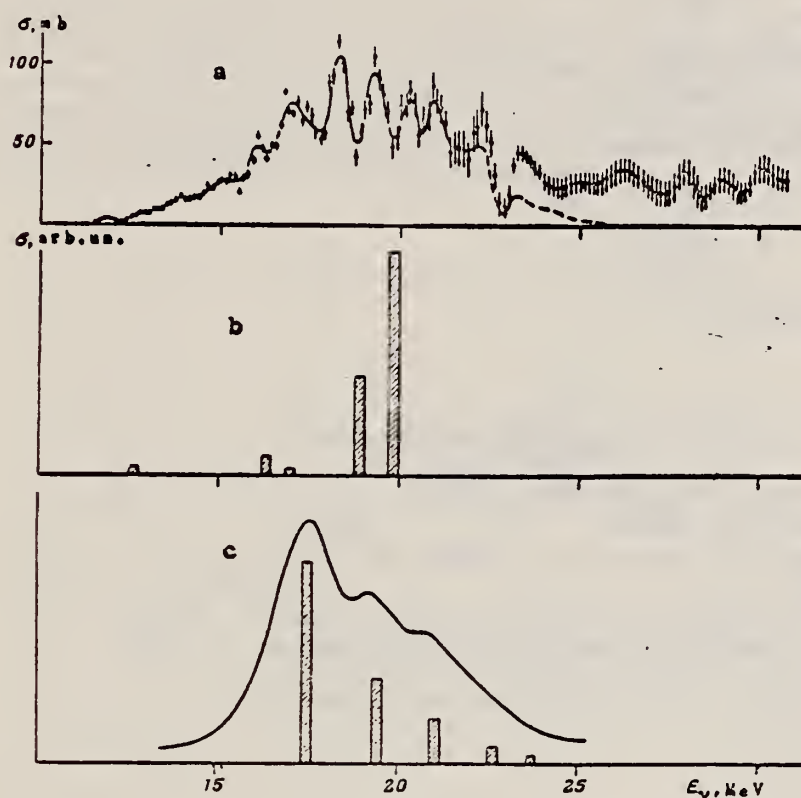


Fig.2. a - The $(\gamma,n) + (\gamma,2n)$ cross section for ^{52}Cr ;
b & c - theoretical absorption cross sections calculated via: b - the theory of finite Fermi systems⁷,
c - the collective dynamic model⁸.

⁷G.G. Bunatyan, Yadernaya fizika 4, 920 (1966). (Trans. Soviet Journal of Nuclear Physics.)

⁸D. Drechsel & C. Toepffer, Nucl. Phys. A100, 161 (1967).

(over)

Characteristics of the Photoneutron Cross Sections (in MeV-mb)

Nucleus	Integral cross sections*				Center of gravity $\sigma(\gamma n) + \sigma(\gamma, 2n)$, MeV	Refs.	Dipole sum rule $60NZ/A$, MeV-mb
	$\sigma(\gamma n) + 2\sigma(\gamma, 2n)$	$\sigma(\gamma n) + \sigma(\gamma, 2n)$	$\sigma(\gamma n)$	$\sigma(\gamma, 2n)$			
⁵¹ V	820 (30)	600 (30)	380 (30)	220 (30)	21,3	Our work	760
	670 (28)	560 (28)	450 (28)	110 (28)		[9]	
	590 (24)					[10]	
	560 (25)					[11]	
⁵² Cr	950 (30)	740	530 (30)	210 (30)	20,4	Our work	775
	600 (24)					[10]	
⁵⁹ Co	1030 (30)	740 (30)	450 (30)	290 (30)	20,2	Our work	880
	730 (28)	590 (28)	450 (28)	140 (28)		[9]	
	870 (29)					[12]	
	840 (25)					[13]	
	660 (28)					[14]	
	630 (25)					[11]	

*The upper integration limits are given in parentheses.

9. S.C.Fultz, R.L.Bramblett, I.T.Caldwell, N.E.Hansen & C.P.Jupiter, Phys. Rev. 128, 2345 (1962).
10. J.Goldenberg & L.Katz, Canadian J. Phys. 32, 49 (1954).
11. B.Nathans & J.Halpern, Phys. Rev. 93, 437 (1954).
12. E.B.Bazhanov, A.P.Komar & A.V.Kulikov, Zh. Eksperim. i teor. fiz. 46, 1497 (1964). (Trans. Soviet Physics - JETP.)
13. P.A.Flournoy, R.S.Tickle & W.D.Whitehead, Phys. Rev. 120, 1424 (1960).
14. G.Baciu, G.C.Bonazzola, B.Minetti, C.Molino, L.Pasqualini & G.Piragino, Nuclear Phys. 68, 178 (1965).

REF.

B.S. Ishkhanov, I.M. Kapitonov, I.M. Piskarev, V.G. Shevchenko,
and O.P. Shevchenko
Yad. Fiz. 11, 485 (1970)
Sov. J. Nucl. Phys. 11, 272 (1970)

ELEM. SYM.

A

Z

Cr

52

24

METHOD

REF. NO.

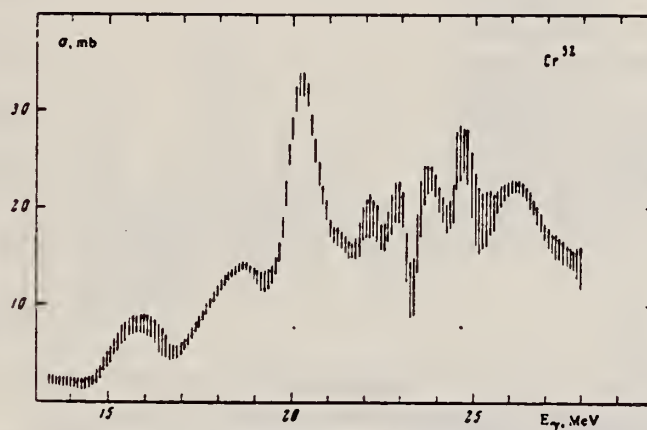
70 Is 4

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, P	ABX	10-30	C	10-30	SCD-D	1-	XXX
		(9.6 - 30)		(9.6 - 30)			

XXX PROB 90

We measured the photoproton cross sections for the nuclei Cr^{52} , Ni^{58} , and Ni^{60} from the threshold to 30 MeV. We registered protons with energy larger than 1 MeV. A number of maxima were obtained in the cross sections. The values of the integral cross sections for Cr^{52} , Ni^{58} , and Ni^{60} are equal respectively to 240, 570, and 320 MeV-mb. The anomalously large cross section for the production of photoprotons for Ni^{58} , and also the shift of the centers of gravity of the photoproton cross sections towards higher excitation energies relative to the photoneutron cross sections in the case of Cr^{52} and Ni^{60} , can be attributed to the influence of analog states.

FIG. 1. Photoproton cross section for Cr^{52} .

Integral characteristics of the photoproton cross sections σ_p , of the photoneutron cross sections σ_n , and of the total absorption cross sections $\sigma_\gamma = \sigma_n + \sigma_p$

Nucleus	$\int_0^{30} \sigma_n dE$	$\int_0^{30} \sigma_p dE$	$\int_0^{30} \sigma_\gamma dE$	$\beta^0 (NZ/A)$	$\int_0^{30} \sigma_p dE / \int_0^{30} \sigma_\gamma dE$	$\bar{E}(\sigma_n) = \frac{\int_0^{30} E \sigma_n dE}{\int_0^{30} \sigma_n dE}$	$\bar{E}(\sigma_p) = \frac{\int_0^{30} E \sigma_p dE}{\int_0^{30} \sigma_p dE}$
	MeV-mb	MeV-mb	MeV-mb	MeV-mb		MeV	MeV
Cr^{52}	730 ± 60	240 ± 50	970 ± 110	775	0.25	20.4 ± 0.3	23.0 ± 0.4
Ni^{58}	310 ± 30	570 ± 60 (100 ± 20)	880 ± 90	870	0.65	21.9 ± 0.3	21.4 ± 0.3
Ni^{60}	620 ± 50	220 ± 50 (60 ± 20)	940 ± 100	895	0.34	20.7 ± 0.3	22.6 ± 0.3

Note. The parentheses contain the integral cross sections of the photoproton reactions for protons with energy $E_p \geq 8$ MeV.

REF. W. B. Walters, J. R. Van Hise, W. L. Switzer, J. P. Hummel
Nucl. Phys. A157, 73 (1970)

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.		
70 Wa 3		egf

METHOD					REF. NO.	
					70 Wa 3	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,2N	RLY	THR-305	C	150-305	ACT-I	4PI
G,pn	RLY	THR-305	C	150-305	ACT-I	4PI

TABLE 1
Summary of measured yield ratios

Target	Bremsstrahlung energy (MeV)	Measured yield ratio
natural Cr	150	$^{48}\text{Cr}/^{48}\text{V} = 0.043 \pm 0.002$
	250	0.047 ± 0.009
	305	0.042 ± 0.002
enriched ^{52}Cr	250	0.025 ± 0.005
natural Fe	250	$^{52}\text{Fe}/^{52}\text{Mn} = 0.037 \pm 0.003$
enriched ^{56}Fe	250	0.024 ± 0.005
		$^{52}\text{Mn}/(^{52}\text{Mn} + ^{25}\text{Mn}) = 0.47 \pm 0.02$
natural Y	150	$^{87}\text{Y}/^{87}\text{Sr} = 12.9 \pm 1.6$
natural Mo	150	$^{90}\text{Mo}/^{90}\text{Nb} = 0.41 \pm 0.05$
	280	0.49 ± 0.05

TABLE 2
Summary of experimental and theoretical ratios of (γ , 2n) to (γ , pn) yields

Target isotope	Bremsstrahlung energy (MeV)	Experimental (γ , 2n)/(γ , pn) yield ratio	Calculated (γ , 2n)/(γ , pn) yield ratio
^{50}Cr	250	0.095 ± 0.025	0.14
^{54}Fe	250	0.10 ± 0.03	0.07
^{89}Y	150	7.4 ± 1.0	6.7
^{92}Mo	150	0.41 ± 0.05	0.15
	280	0.49 ± 0.05	0.16

METHOD

REF. NO.

71 Ba 2

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	12-14	C	12, 14	TOF-D		135
		(12.3-13.7)					

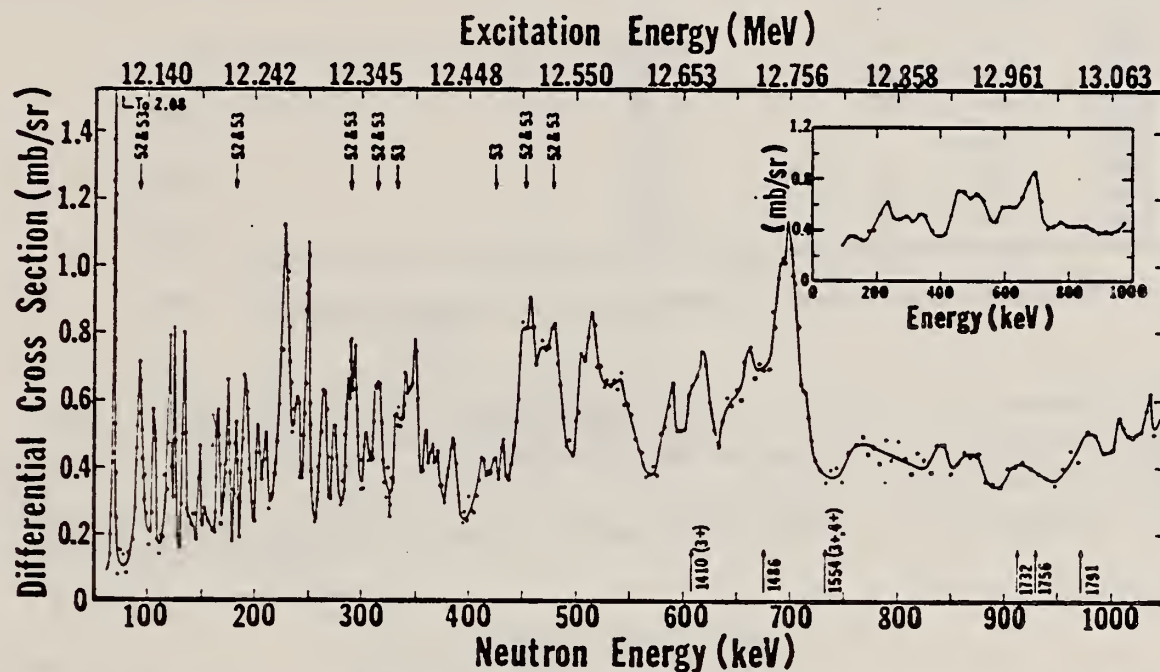


FIG. 14. The 135° differential threshold photoneutron cross section for ^{52}Cr (see caption to Fig. 4). The arrows below the data indicate the positions of isobaric analogs of low-lying states of ^{52}V . Next to the arrows are the values of J^π and the energy in keV of these low-lying states.

Also see:

R. J. Baglan et al.
Phys. Rev. C3, 2475
(1971)

[over]

TABLE VI (Continued)

Nucleus	E_L (keV)	E_{ex} (MeV)	$g_\gamma \Gamma_{\gamma 0} \Gamma_n / \Gamma$ (eV)	GS or ES	J^π	$\Gamma_{\gamma 0}$ (eV)	E_n (keV) (This work)	E_n (keV) from neutron- induced reactions		
								(Ref. a)	(Ref. b)	(Ref. c)
⁵² Cr	68.2	12.107	0.69	GS			73.0			
	105	12.145	0.40	GS			112			
	121	12.161	0.71	GS			129			
	125	12.165	0.35	GS			133			
	133	12.173	0.60	GS			141			
	147	12.188	0.31				156			
	166	12.208	0.50	GS			176			
	175	12.217	0.62	GS			185			
	191	12.233	0.95	GS			202			
	203	12.245	0.49	GS			215			
	210	12.253	0.43	GS			222			
	229	12.272	2.47	GS			242			
	238	12.282	0.71	GS			251			
	249	12.293	1.22	GS			263			
	264	12.308	0.95	GS			279			
	274	12.319	0.61	GS			289			
	286	12.331	0.55				301			
	293	12.338	0.59				309			
	341	12.388	0.78	GS			359			
	349	12.396	1.04	GS			368			
	385	12.432	0.66	GS			405			

^aSee Ref. 17.^bSee R. W. Hockenbury, Z. M. Bartolome, J. R. Tatarczuk, W. R. Moyer, and R. C. Block, Phys. Rev. 178, 1746 (1969).^cSee Ref. 19.¹⁷C.D. Bowman, E.G. Bilpuch, and H.W. Newson, Ann. Phys. (N.Y.) 17, 319 (1962).^bSee R.W. Hockenbury, Z.M. Bartolome, J.R. Tatarczuk, W.R. Moyer, and R.C. Block, Phys. Rev. 178, 1746 (1969).¹⁹R.G. Steiglitz, Ph.D. thesis, Rensselaer Polytechnic Institute, 1970 (unpub.)

ELEM. SYM.	A	Z
Cr	52	24

METHOD	REF. NO.	
	72 De 8	hvm

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E'	FMF	1, 3	D	80	MAG-D		DST

1=1.43, 3=3.6 MEV

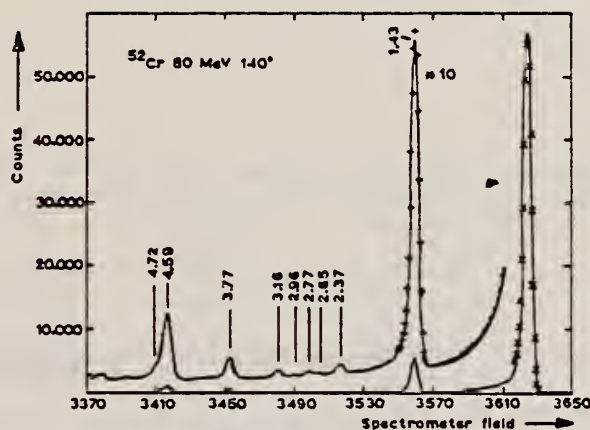


Fig. 10. A typical spectrum of elastic and inelastic scattered electrons from ^{52}Cr . The drawn curve is the peak fitted spectrum.

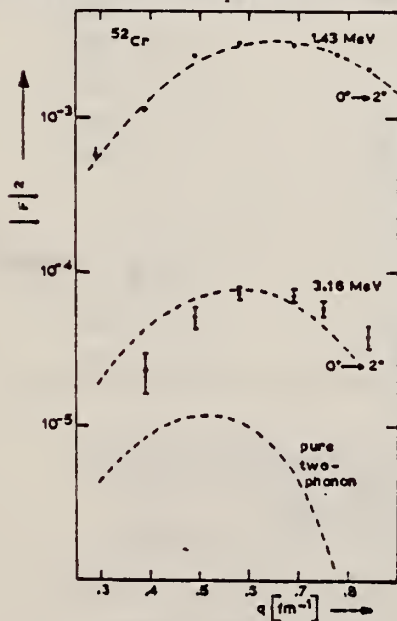


Fig. 11. Experimental form factor curves for the 1.43 and 3.16 MeV level in ^{52}Cr . The dashed curves represent the best fit results in Born approximation of the mixed one- and two phonon form factors. Also drawn is the two phonon prediction for the 3.16 MeV level with the radius and collective parameters fixed by the one phonon fit to the 1.43 MeV level.

REF.

S. Penner, J.W. Lightbody, Jr., S.P. Fivozinsky, H. Crannell,
P.L. Hallowell, and M. Finn
PICNS-72, 49 (1972) Sendai

ELEM. SYM.

A

Z

Cr

52

24

METHOD

REF. NO.

72 Pe 2

hvm

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1, 3	D	40-110	MAG-D		128

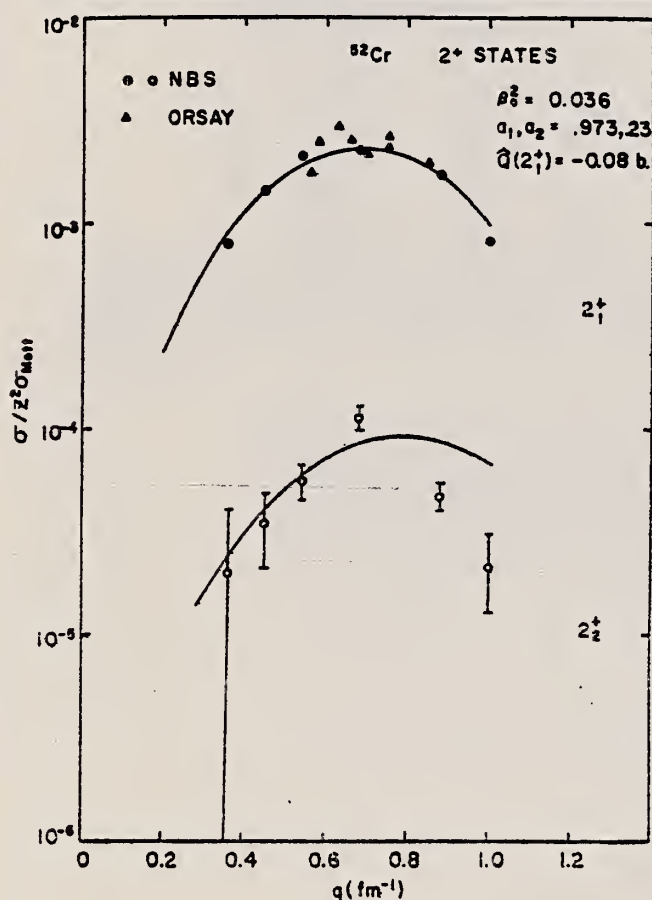


Fig. 1. Form factors for excitation of the first and second 2^+ states in ^{52}Cr . The smooth curves are the best fits of the anharmonic vibrator model.

1=1.434, 3=3.16 MEV

Table 2. First Excited State Static Quadrupole Moments

Nucleus	Q, barns	
	electron scattering	reorientation effect
^{48}Ti	$-0.177 \pm .008^b$	$-0.22 \pm .08^c$ $-0.135 \pm .082^d$ $-0.38 \pm .13^e$
^{52}Cr	$-0.082 \pm .016^a$	$-0.07 \pm .13^f$
^{60}Ni	$-0.104 \pm .018^b$	$0 \pm .13^g$
^{64}Zn	$-0.135 \pm .016^b$	-
^{70}Zn	$-0.21 \pm .03^b$	-
^{110}Pd	$-0.28 \pm .03^a$	$(-0.27 \text{ OR } -0.48) \pm .05^h$ $(-0.45 \text{ OR } -0.72) \pm .12^i$
^{114}Cd	$-0.29 \pm .03^a$	$-0.32 \pm .08^j$
^{118}Sn	$-0.14 \pm .03^a$	$+0.09 \pm .13^k$

a) New preliminary values

b) From Ref. (1)

c) O. Hausser, *et al.*, Nucl. Phys. A150, 417 (1970)d) P.M.S. Lesser, *et al.*, University of Rochester Annual Report, 1970 (unpublished)e) N.V. deCastro-Faria, *et al.*, Nucl. Phys. A174, 37 (1971)

f) D. Cline, University of Rochester Report UR-NSRL-40, 1971 (unpublished)

g) D. Cline, *et al.*, Nucl. Phys. A133, 445 (1969)h) R. Beyer, *et al.*, Phys. Rev. C2, 1469 (1970)i) R.P. Harper, *et al.*, Nucl. Phys. A162, 161 (1971)j) Z. Berant, *et al.*, Phys. Rev. Letters 27, 110 (1971)k) A.M. Kleinfeld, *et al.*, Nucl. Phys. A154, 499 (1970)

REF.

D. Branford, G.S. Foote, R.A.I. Bell, D.C. Weissner,
F.G.P. Huang and R.B. Watson
PICNS-73, Vol.II, p.943 (1973) Asilomar

ELEM. SYM.

A

Z

Cr

52

24

METHOD

REF. NO.

73 Br 7

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,A	ABX	- 25	D	16	NAI-D		DST

NO ANG DST DATATable 1. Preliminary Results with Relative Errors; Absolute Errors \approx 30%

Reaction	$\int \sigma(\gamma_0, \alpha_0) dE$ mb. MeV	$\int \sigma(\gamma_1, \alpha_0) dE$ mb. MeV	Excitation Energy (MeV)
$^{40}\text{Ar}(\alpha, \gamma)^{44}\text{Ca}$	1.4 ± 0.3	0.42 ± 0.08	15.5
$^{48}\text{Ti}(\alpha, \gamma)^{52}\text{Cr}$	3.0 ± 0.6	0.48 ± 0.10	17.0
$^{56}\text{Fe}(\alpha, \gamma)^{60}\text{Ni}$	7.8 ± 1.5	1.52 ± 0.30	16.0

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.	73 Ho 4	
	egf	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1- 5	D	209	MAG-D		DST

1.43, 2.37, 4.56

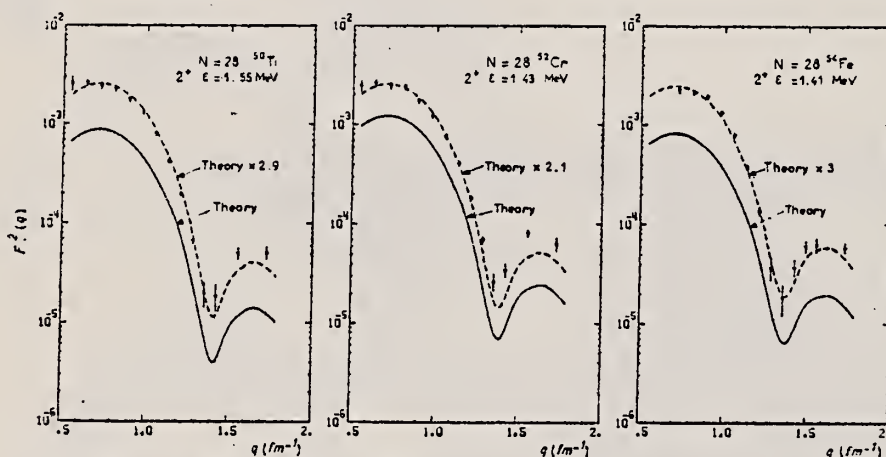


Fig. 5a. Squared inelastic form factor for 2⁺ states of the N = 28 isotones.

TABLE 3
Inelastic cross sections for E_e = 209 MeV on ⁵²Cr

θ (deg.)	(2 ⁺)ε = 1.43 MeV dσ/dΩ (mb/sr)	(3 ⁻)ε = 4.56 MeV dσ/dΩ (mb/sr)	(4 ⁺)ε = 2.37 MeV dσ/dΩ (mb/sr)
30	0.353 E-1 ± 0.460 E-2		
35	0.201 E-1 ± 0.140 E-2	0.313 E-2 ± 0.115 E-2	
40	0.110 E-1 ± 0.800 E-3	0.235 E-2 ± 0.360 E-3	
45	0.653 E-2 ± 0.420 E-3	0.169 E-2 ± 0.110 E-3	
50	0.312 E-2 ± 0.210 E-3	0.125 E-2 ± 0.900 E-4	0.292 E-3 ± 0.400 E-4
55	0.146 E-2 ± 0.900 E-4	0.873 E-3 ± 0.430 E-4	0.233 E-3 ± 0.160 E-4
60	0.633 E-3 ± 0.390 E-4	0.585 E-3 ± 0.310 E-4	0.176 E-3 ± 0.120 E-4
65	0.241 E-3 ± 0.150 E-4	0.373 E-3 ± 0.170 E-4	0.129 E-3 ± 0.700 E-5
70	0.780 E-4 ± 0.540 E-5	0.231 E-3 ± 0.130 E-4	0.925 E-4 ± 0.590 E-5
75	0.220 E-4 ± 0.200 E-5	0.136 E-3 ± 0.800 E-5	0.615 E-4 ± 0.380 E-5
80	0.625 E-5 ± 0.120 E-5	0.697 E-4 ± 0.440 E-5	0.387 E-4 ± 0.250 E-5
85	0.622 E-5 ± 0.900 E-6	0.380 E-4 ± 0.230 E-5	0.235 E-4 ± 0.180 E-5
95	0.854 E-5 ± 0.670 E-6	0.856 E-5 ± 0.690 E-6	0.879 E-5 ± 0.890 E-6
110	0.312 E-5 ± 0.460 E-6	0.980 E-6 ± 0.184 E-6	0.102 E-5 ± 0.190 E-6

Energy level diagram given by ref. ²⁴). Levels excited in our experiment are shown with solid lines, dashed lines correspond to other levels. The experimental values are normalized on our elastic cross sections considered as reference values.

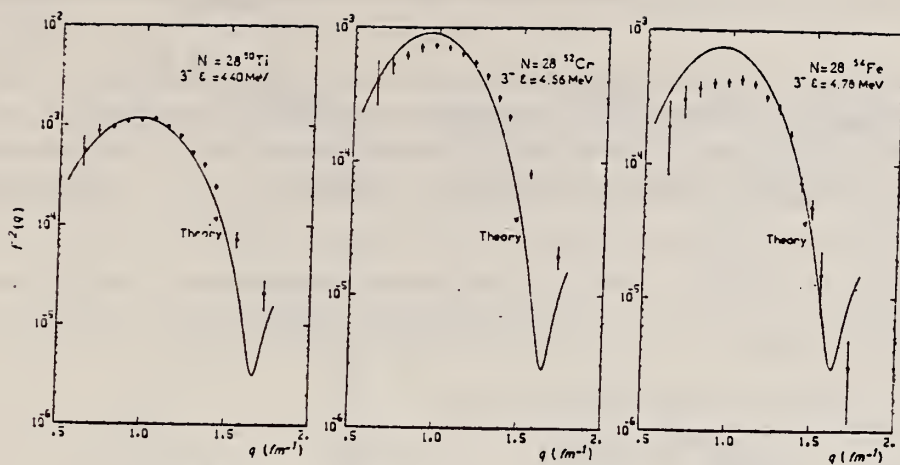


Fig. 6a. Squared inelastic form factor for 3^- states of the $N = 28$ isotones.

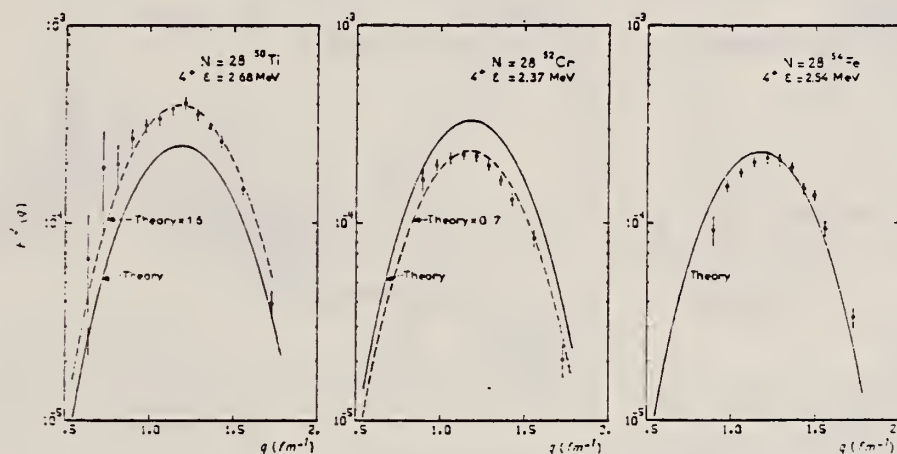


Fig. 7a. Squared inelastic form factor for 4^+ states of the $N = 28$ isotones.

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.		
74 Fo 4		egf

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G, A	ABX	15- 20	D	6- 11	NAI-D		90

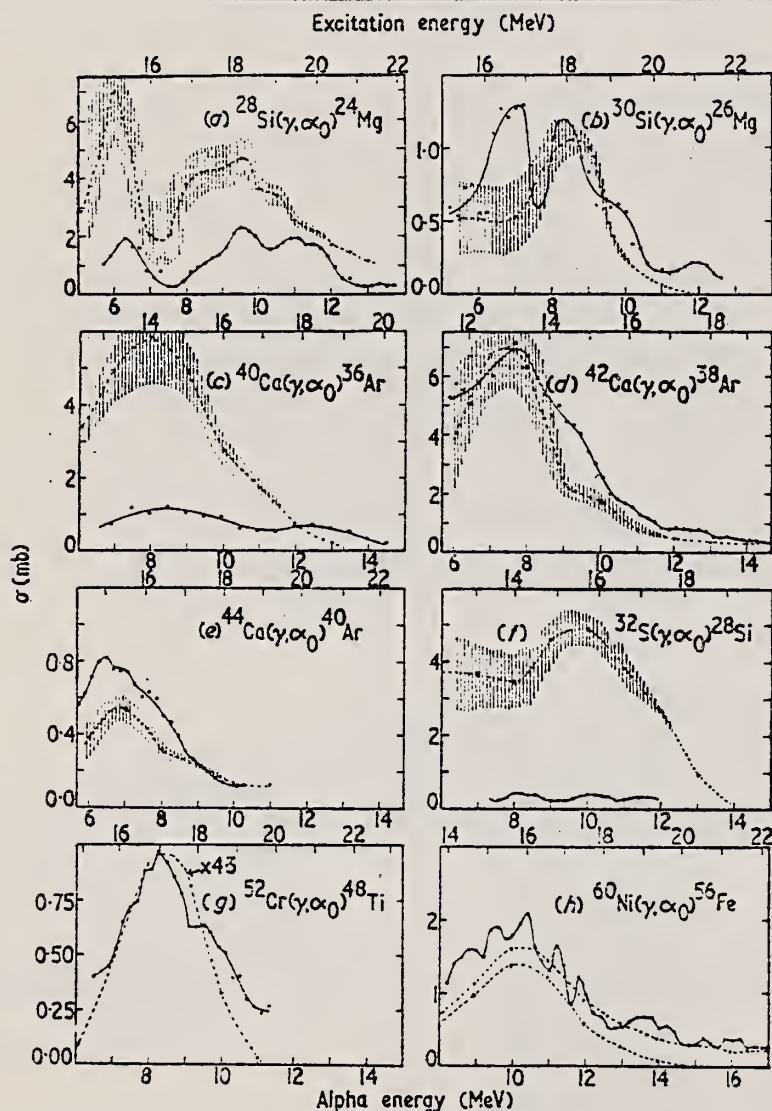


Figure 1. Excitation functions for the (γ, α) reaction obtained from α capture data using the principle of detailed balance. The data shown in (a) and (f) are from Meyer-Shutzmeister *et al* (1968). Those in (b) are from Watson *et al* (1973). The relative experimental errors are approximately $\pm 10\%$. The absolute errors are $\pm 25\%$. The broken curves are the results of calculations (see text). The vertical lines indicate the relative errors due to uncertainties in the total photonuclear cross sections where they are greater than $\pm 10\%$. The crosses indicate the energies at which transmission coefficients were calculated.

REF.

G. S. Foote, D. Branford, D. C. Weisser, N. Shikazono,
R.A.I. Bell, F.C.P. Huang
Nucl. Phys. A263, 349 (1976)

ELEM. SYM.	A	Z
Cr	52	24

METHOD	REF. NO.	
	76 Fo 2	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
A, G	ABX	15- 21	D	6- 12	NAI-D		DST

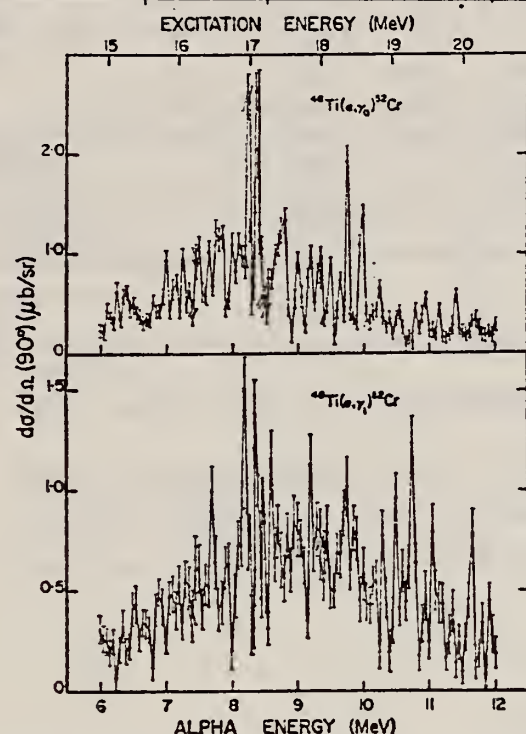


Fig. 4. Absolute differential cross sections for the $^{48}\text{Ti}(\alpha, \gamma_0)^{52}\text{Cr}$ and $^{48}\text{Ti}(\alpha, \gamma_1)^{52}\text{Cr}$ reactions measured at 90° to the beam direction versus bombarding energy. The absolute error is 30 %. The continuous line is a guide to the eye.

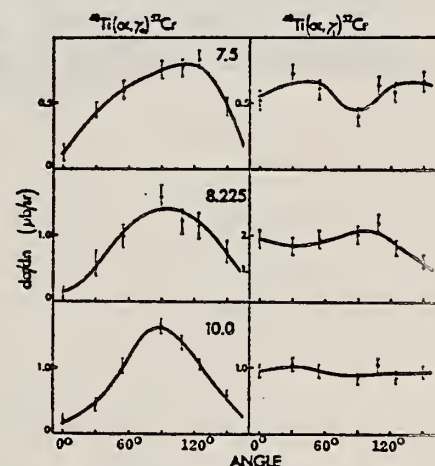


Fig. 7. Angular distribution measurements for the $^{48}\text{Ti}(\alpha, \gamma_0)^{52}\text{Cr}$ reaction and the $^{48}\text{Ti}(\alpha, \gamma_1)^{54}\text{Cr}$ reaction at the bombarding energies (MeV) indicated. Only relative statistical errors are shown. The continuous lines represent Legendre polynomial fits to the data.

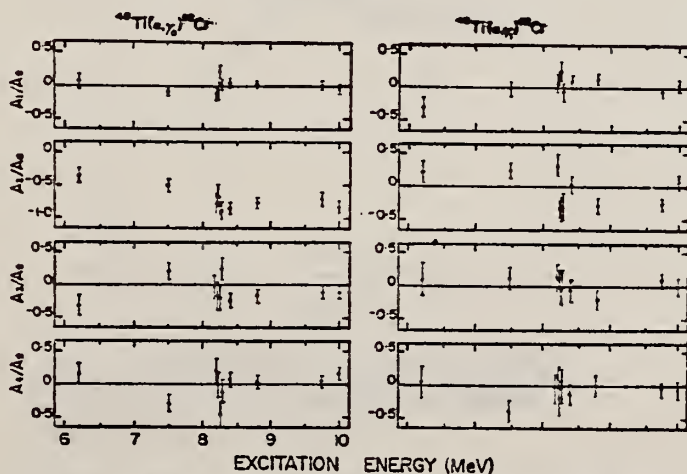


Fig. 10. Normalised Legendre polynomial coefficients determined by linear least squares fitting of the γ -ray distributions measured for the $^{48}\text{Ti}(\alpha, \gamma_0)^{52}\text{Cr}$ and $^{48}\text{Ti}(\alpha, \gamma_1)^{54}\text{Cr}$ reaction.

(over)

TABLE 3
Comparisons of energy integrated (γ , α) cross sections, peak energies of the broad structures in the (γ , α) excitation functions and the particle threshold energies

Final ^{a)} nucleus	Range of integration (MeV)	$\int \sigma(\gamma, \alpha) dE$ ^{b)} (mb · MeV)	$\int \sigma(\gamma, \alpha) dE$ ^{b)} cds (%)	Particle threshold energies			E ^{c)} (MeV)	Exp. peak energy (MeV)	GDR energy (MeV)	Refs.
				α (MeV)	n (MeV)	p (MeV)				
²⁸ Si	14.5-22.5	9.6	2.3	9.99	17.18	11.59	15.2	18.0	20	¹⁾
³⁰ Si	14.0-22.0	5.3	1.2	10.65	10.62	13.51	15.7	16.5	18	¹⁾
³² Si	13.1-22.7	2.7	0.57	6.95	15.09	8.87	13.0	16	20	¹⁾
⁴⁰ Ca	12.5-22.2	4.8	0.8	7.04	15.62	8.33	14.2	14.0	20	⁶⁾
⁴² Ca	11.0-20.5	30.2	4.8	6.25	11.49	10.28	13.3	13.0	17.4	this work
⁴⁴ Cu	13.5-18.8	2.6	3.09	8.84	11.13	12.16	15.9	15.3	17	this work
⁴⁴ Ca*	13.5-18.8	0.76	0.12				15.9		18.5	this work
⁴⁴ Ti	10.5-20.6	6.1	0.9	5.18	5.18	8.66	13.9	14.0		¹⁵⁾
⁵² Ti	12.7-20.4	≈ 0.3	≈ 0.04	7.67	7.80	13.53	16.1			¹⁵⁾
⁵² Cr	15.0-20.5	2.9	0.38	9.35	12.05	10.52	17.6	17.0	18	this work
⁵² Cr*	15.0-20.5	0.51	0.07				17.6			this work
⁶⁰ Ni	13.9-22.8	9.6	1.07	6.29	11.39	9.53	15.7	15.8	16.6	³⁾
⁶⁰ Ni*	13.9-22.8	1.7	0.18	4.96			15.7		17.9	³⁾

^{a)} The asterisk denotes first excited state.

^{b)} The errors are approximately $\pm 30\%$.

^{c)} E is the α -particle threshold energy plus Coulomb barrier height (see text).

- ¹ L. Meyer-Schutzmeister et al., Nucl. Phys. A108, 180 (1968).
- ³ G. S. Foote et al., Nucl. Phys. A220, 505 (1974).
- ⁶ R. B. Watson et al., Nucl. Phys. A203, 209 (1973).
- ¹⁵ R. E. Peshel et al., Nucl. Phys. A232, 269 (1974).

REF.

J.W. Lightbody, Jr., S. Penner, S.P. Fivozinsky,
P.W. Hallowell and Hall Crannell
Phys. Rev. C14, 952 (1976)

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.		76 Li 5
		hug

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1, 3	D	39-111	MAG-D		127
		(1.43, 3.16)					

LEVEL 1.43, 3.16TABLE V. ^{52}Cr Tassie model transition charge distribution parameters.

Excited state		c_{π}/c	z_{π}/z	$B(E2) e^2\text{fm}^4$	$\chi^2/(N-P)$	$N-P$
1.43 MeV	Present data	0.956 ± 0.040	0.905 ± 0.115	634 ± 39	2.2	3
2 ⁺ State	de Bie (Ref. 19)	0.933 ± 0.010	0.991	761 ± 30	1.6	8
	Towsley <i>et al.</i> (Ref. 20)			666 ± 29		
3.16 MeV	Present data	0.901 ± 0.041	0.991^a	12.4 ± 2.3	2.5	4
2 ⁺ State	de Bie	0.931 ± 0.040	0.991^a	15.5 ± 2.0	1.0	5

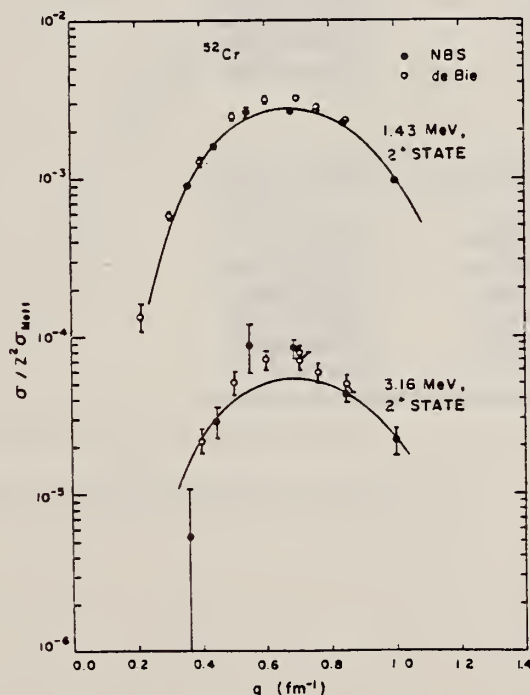
^a By assumption, from de Bie.

FIG. 4. Cross section for ^{52}Cr in units of $Z^2 \sigma_{\text{Mott}}$ for the 1.43 and 3.16 MeV, σ_{Mott} 2⁺ states. Also shown are the data of de Bie. Tassie model fits to the NBS data alone are given by the solid curves.

(over)

TABLE III. Ratios of inelastic scattering cross sections to $Z^2\sigma_{\text{Mott}}$.

^{52}Cr				
E_i (MeV)	θ (deg)	1.43 MeV, 2^+ state	3.16 MeV, 2^+ state	
39.38	127.74	$(0.90 \pm 0.04) \cdot 10^{-3}$	$(0.55 \pm 0.55) \cdot 10^{-5}$	
49.44	127.74	$(0.159 \pm 0.006) \cdot 10^{-2}$	$(0.29 \pm 0.07) \cdot 10^{-4}$	
59.84	127.71	$(0.26 \pm 0.02) \cdot 10^{-2}$	$(0.89 \pm 0.30) \cdot 10^{-4}$	
75.22	127.71	$(0.265 \pm 0.007) \cdot 10^{-2}$	$(0.842 \pm 0.012) \cdot 10^{-4}$	
92.73	127.74	$(0.222 \pm 0.005) \cdot 10^{-2}$	$(0.428 \pm 0.052) \cdot 10^{-4}$	
110.20	127.69	$(0.97 \pm 0.02) \cdot 10^{-3}$	$(0.222 \pm 0.044) \cdot 10^{-4}$	
^{110}Pd				
E_i (MeV)	θ (deg)	0.374 MeV, $2^+_{1/2}$ state	0.81 MeV, $2^+_{1/2}$ state	
39.38	127.74	$(0.35 \pm 0.03) \cdot 10^{-2}$	$(0.45 \pm 0.14) \cdot 10^{-4}$	
49.44	127.74	$(0.40 \pm 0.02) \cdot 10^{-2}$	$(0.10 \pm 0.01) \cdot 10^{-3}$	
59.84	127.71	$(0.40 \pm 0.02) \cdot 10^{-2}$	$(0.10 \pm 0.01) \cdot 10^{-3}$	
75.22	127.71	$(0.233 \pm 0.003) \cdot 10^{-2}$	$(0.86 \pm 0.07) \cdot 10^{-4}$	
92.73	127.74	$(0.40 \pm 0.05) \cdot 10^{-3}$	$(0.48 \pm 0.06) \cdot 10^{-4}$	
110.20	127.69	$(0.23 \pm 0.01) \cdot 10^{-3}$	$(0.17 \pm 0.17) \cdot 10^{-5}$	
^{114}Cd				
E_i (MeV)	θ (deg)	0.558 MeV, $2^+_{1/2}$ state	1.208 MeV, $2^+_{1/2}$ state	
39.38	127.74	$(0.20 \pm 0.02) \cdot 10^{-2}$	$(0.46 \pm 0.07) \cdot 10^{-4}$	
49.44	127.74	$(0.28 \pm 0.02) \cdot 10^{-2}$	$(0.40 \pm 0.06) \cdot 10^{-4}$	
59.84	127.71	$(0.220 \pm 0.014) \cdot 10^{-2}$	$(0.58 \pm 0.11) \cdot 10^{-4}$	
75.22	127.71	$(0.118 \pm 0.005) \cdot 10^{-2}$	$(0.34 \pm 0.04) \cdot 10^{-4}$	
92.73	127.74	$(0.204 \pm 0.007) \cdot 10^{-3}$	$(0.11 \pm 0.04) \cdot 10^{-4}$	
110.20	127.69	$(0.155 \pm 0.007) \cdot 10^{-3}$	$(0.61 \pm 0.35) \cdot 10^{-5}$	
^{118}Sn				
E_i (MeV)	θ (deg)	1.294 MeV, $2^+_{1/2}$ state	2.112 MeV, $2^+_{1/2}$ state	2.266 MeV, 3^- state
39.38	127.74	$(0.65 \pm 0.04) \cdot 10^{-3}$	$(0.68 \pm 1.05) \cdot 10^{-5}$	$(0.18 \pm 0.02) \cdot 10^{-3}$
49.44	127.74	$(0.88 \pm 0.04) \cdot 10^{-3}$	$(0.26 \pm 0.69) \cdot 10^{-5}$	$(0.40 \pm 0.01) \cdot 10^{-3}$
59.84	127.71	$(0.84 \pm 0.03) \cdot 10^{-3}$	$(0.21 \pm 0.06) \cdot 10^{-4}$	$(0.63 \pm 0.02) \cdot 10^{-3}$
75.22	127.71	$(0.36 \pm 0.02) \cdot 10^{-3}$	$(0.5 \pm 7.4) \cdot 10^{-6}$	$(0.84 \pm 0.02) \cdot 10^{-3}$
75.02	127.81	$(0.34 \pm 0.02) \cdot 10^{-3}$	$(0.47 \pm 0.39) \cdot 10^{-5}$	$(0.82 \pm 0.01) \cdot 10^{-3}$
92.73	127.74	$(0.50 \pm 0.09) \cdot 10^{-4}$	$(0 \pm 0.19) \cdot 10^{-4}$	$(0.60 \pm 0.01) \cdot 10^{-3}$
110.20	127.69	$(0.85 \pm 0.10) \cdot 10^{-4}$	$(0 \pm 0.8) \cdot 10^{-5}$	$(0.14 \pm 0.01) \cdot 10^{-3}$

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.		hg
78 Ma 10		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	12-68	C	30-68	ACT - I		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

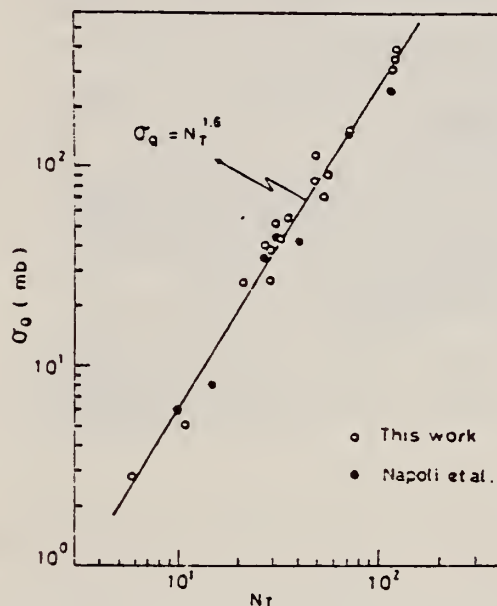


Fig. 2. Yield per equivalent quanta versus target neutron number.

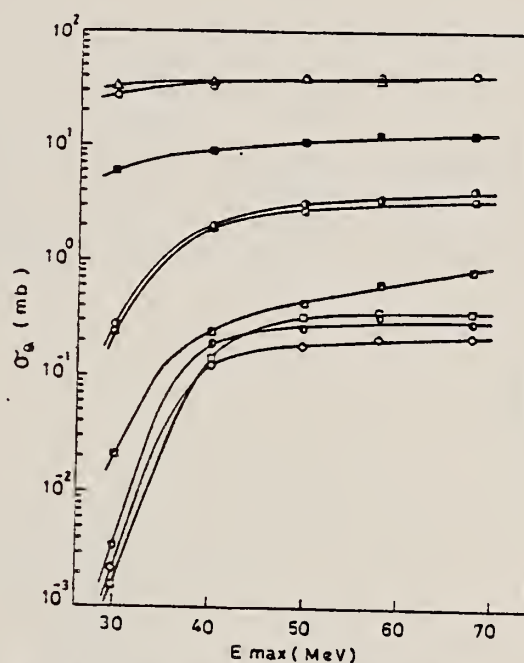


Fig. 5. Activation yield curves for the reactions on Cr, Mn and Fe.

○ $^{52}\text{Cr}(\gamma, n)^{51}\text{Cr}$, ● $^{50}\text{Cr}(\gamma, pn)^{48}\text{V}$, ◐ $^{50}\text{Cr}(\gamma, 2n)^{48}\text{Cr}$,
 △ $^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$, ■ $^{57}\text{Fe}(\gamma, p)^{56}\text{Mn}$, ▣ $^{54}\text{Fe}(\gamma, pn)^{52}\text{Mn}$,
 ▤ $^{56}\text{Fe}(\gamma, pn)^{54}\text{Mn}$, □ $^{56}\text{Fe}(\gamma, zn)^{51}\text{Cr}$, ◇ $^{54}\text{Fe}(\gamma, 2n)^{52}\text{Fe}$.

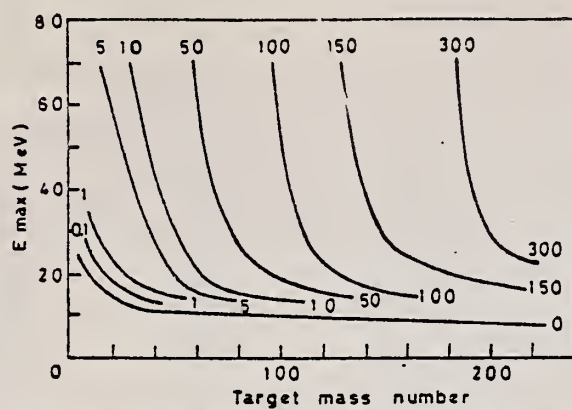


Fig. 9. Yields of the (γ, n) reactions as a function of bremsstrahlung maximum energy and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

REF. V.N. Polishchuk, n.G. Shevchenko, N.G. Afanas'ev, A.A. Khomich,
A.Yu. Buki, B.V. Mazan'ko
Yad. Fiz. 27, 1145 (1978)
Sov. J. Nucl. Phys. 27, 607 (1978)

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.		
78 Po 3		hg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	BEL	1	D	120, 227	MAG-D		DST

Inelastic electron scattering has been used to measure the form factors of the 1.43-MeV level in ^{52}Cr and the 0.56-, 1.01-, 1.29-, and 1.97-MeV levels in ^{53}Cr . The measurements were made with an initial electron energy $E_0 = 90, 120, \text{ and } 226 \text{ MeV}$ in the momentum-transfer region $0.85\text{--}1.7 \text{ F}^{-1}$ and $0.74\text{--}1.15 \text{ F}^{-1}$ respectively for ^{52}Cr and ^{53}Cr . For these states reduced transition probabilities $B(E2)^\dagger$ were obtained, respectively $800 \pm 80, 100 \pm 20, 170 \pm 18, 335 \pm 30, \text{ and } 190 \pm 15 \text{ e}^2 \cdot \text{F}^4$. The results obtained are discussed in terms of the excited-core model.

1 LEVEL 1.43 MEV

PACS numbers: 25.30.Cg, 27.40. + z, 23.20.Ck

TABLE I. Reduced probabilities for transition from the ground state of the nucleus to excited states for the isotopes $^{52,53}\text{Cr}$.

Nucleus	Transition $J_i \rightarrow J_f$	$E, \text{ MeV}$	λ	Value of $B(E2)/1, e^2 \text{ F}^2 A$									
				Experiment					Theory				
				Our data	[7]	[8]	[9]	[1]		[11]	[12]	[13]	[14]
								Generalized model					
								$e_n = e$	$e_n = 0$				
								Shell model					
^{52}Cr	$2^+ \rightarrow 0^+$	0.56	100 \pm 20	115 \pm 12	110 \pm 20	89	98	50	20	73	59	62.5	66.3
	$4^+ \rightarrow 2^+$	1.01	170 \pm 10	72 \pm 8	20 \pm 20	52	113	33	33	53	162	20.3	64.5
	$6^+ \rightarrow 4^+$	1.29	335 \pm 30	300 \pm 40	260 \pm 60	138	120	18	136	126	59	244	
	$8^+ \rightarrow 6^+$	1.97	190 \pm 15				64	55	132	50		169	160
	$10^+ \rightarrow 8^+$	2.32					53						
				Our data	[7]	[10]	[10]	[15]		[16]		[17]	
								$e_n = 0.6$	$e_n = 0.7$				
^{52}Cr	$0 \rightarrow 2^+$	1.43	2	800 \pm 80	720 \pm 80	720	761 \pm 30	610	720	940			

¹⁾ Calculation carried out for $M_{22} = 25 \text{ e} \cdot \text{F}^2$ and $\xi = -0.169 \text{ MeV}$, $\eta = -0.0002 \text{ MeV} \cdot \text{e}^{-2} \cdot \text{F}^{-4}$.

²⁾ Calculation carried out for $M_{22} = 35 \text{ e} \cdot \text{F}^2$ and $\xi = -0.125 \text{ MeV}$, $\eta = -0.00055 \text{ MeV} \cdot \text{e}^{-2} \cdot \text{F}^{-4}$.

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.	79Ku4	
	hg	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	7-10	C	14	SCD-D		DST

Abstract: The resonance scattering of electron bremsstrahlung from natural chromium and iron targets has been studied for photon energies up to 12 MeV. Seven γ -transitions of energies higher than 7 MeV were observed for each of the targets, which suggests seven resonant levels in each of ^{52}Cr and ^{56}Fe at excitation energies above 7 MeV. The spins of these levels were all assigned to be 1 from the relative yields at scattering angles of 125° and 150° . Radiative widths of these levels were obtained. A discussion is made about the possibility that these levels are T_z components of the M1 giant resonance in ^{52}Cr and ^{56}Fe .

7 LEVELS

E NUCLEAR REACTIONS ^{52}Cr , $^{56}\text{Fe}(\gamma, \gamma)$ bremsstrahlung $E_\gamma = 14$ MeV; measured E_γ , $I_\gamma(\theta = 125^\circ, 150^\circ)$; ^{52}Cr , ^{56}Fe deduced levels, J , Γ_γ . Natural targets.

TABLE 2

Electromagnetic transitions in ^{11}B used for calibration of $N\epsilon\Omega$ ^{a)}

Initial state	J^π	Γ (eV)	Branching ratios (%) to final states ^{b)}			
			g.s.	2.125	4.445	5.021
4.445	$\frac{3}{2}^-$	0.610 ± 0.030	100 ^{c)}			
5.021	$\frac{3}{2}^-$	1.80 ± 0.13 ^{d)}	84 ± 2 ^{e)}	16 ± 2 ^{f)}		
7.286	$\frac{3}{2}^+$	1.17 ± 0.26 ^{d)}	87 ± 2		5.5 ± 1	7.5 ± 1
8.920 ^{g)}	$\frac{3}{2}^-$	4.20 ± 0.52 ^{d)}	95 ± 1		5 ± 0.5	

^{a)} Ref. ⁹⁾ except where shown.

^{b)} Ref. ⁹⁾.

^{c)} $\delta = -0.19 \pm 0.15$ [ref. ⁹⁾].

^{d)} Ref. ⁷⁾.

^{e)} $\delta = 0.03 \pm 0.05$ [ref. ⁹⁾].

^{f)} $\delta = -0.05 \pm 0.20$ [ref. ⁹⁾].

^{g)} $\delta = -0.11 \pm 0.04$ [ref. ¹⁰⁾].

TABLE 3

Electromagnetic transitions in ^{24}Mg used for calibration of $N\epsilon\Omega$ ^{a)}

Initial state	J^π	Γ (eV)	Branching ratios (%) to final states	
			g.s.	1.369
9.966	1^-	8.8 ± 2.3	65 ± 2	35 ± 2
10.712	1^+	19.9 ± 1.8	78 ± 4	22 ± 4

^{a)} Ref. ¹¹⁾.

TABLE 5
Summary of the experimental results of ^{56}Fe

Level energy (MeV)	$I(150^\circ)/I(125^\circ)$	J	Γ_γ (eV)	$B(\text{M1}, 1^+ \rightarrow 0^+) b)$ (μ_N^2)
6.927	1.27 ± 0.37	1	1.10 ± 0.29	0.29
7.212	1.29 ± 0.44	1	0.77 ± 0.22	0.18
8.131	1.30 ± 0.27	1	3.55 ± 0.74	0.57
8.243	1.37 ± 0.19	1	5.75 ± 0.92	0.89
8.538	1.35 ± 0.27	1	4.92 ± 0.95	0.68
10.479	1.32 ± 0.27	1	3.44 ± 0.64	0.26
11.133	1.17 ± 0.28	1	2.08 ± 0.52	0.13

^{a)} Deduced on the assumption of 100% ground-state transition.

^{b)} Deduced on the assumption of even parity.

METHOD

REF. NO.

79Ts2

hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, P	ABX	15-26	C	15-26	MAG-D		DST
				(15.8-26)			

Abstract: The differential cross sections at 90° for the $^{51}\text{V}(e, p_0)^{50}\text{Ti}$ and $^{52}\text{Cr}(e, p_0 + p_1)^{51}\text{V}$ reactions have been measured over the giant dipole resonance region. These cross sections were used to obtain the differential cross sections of the $^{51}\text{V}(\gamma, p_0)^{50}\text{Ti}$ and $^{52}\text{Cr}(\gamma, p_0 + p_1)^{51}\text{V}$ reactions. The results show two peaks that appear at the same energies as the main peaks of the (γ, n) and (γ, p) cross section for both nuclei. The angular distributions of protons from the (e, p) reaction have also been measured at several points of the incident electron energy. The coefficients A_2 obtained by fitting with a series of Legendre polynomials, $W(\theta) = 1 + A_1 P_1(\cos \theta) + A_2 P_2(\cos \theta)$, varies with excitation energy. These results are discussed in terms of the direct-semidirect process considering isospin effects in the giant dipole resonance.

V-PHOTON ANL, P=P0+P1

NUCLEAR REACTIONS $^{51}\text{V}, ^{52}\text{Cr}(e, p_0), (\gamma, p_0), E = 15.0-26.0$ MeV; measured $\sigma(E, \theta)$ at $\theta = 90^\circ$, measured $\sigma(E, \theta)$ at several E -values for ^{51}V and at $E = 21.4$ MeV for ^{52}Cr . Deduced $\sigma(E, \theta)$ for $^{51}\text{V}(\gamma, p_0)$ and for $^{52}\text{Cr}(\gamma, p_0 + p_1)$ at $\theta = 90^\circ$; natural target (^{51}V), enriched target (^{52}Cr).

TABLE 2
Experimental results of the (γ, p_0) reactions

	$\frac{d\sigma(\gamma, p_0)dE}{d\Omega} (90^\circ)$ (MeV · mb/sr)	$4\pi \frac{d\sigma(\gamma, p_0)dE}{d\Omega}$ (MeV · mb)	$\frac{d\sigma(\gamma, p)dE}{d\Omega}$ (MeV · mb/sr)	$\frac{d\sigma(\gamma, p_0)dE}{d\Omega} / \frac{d\sigma(\gamma, p)dE}{d\Omega}$
^{51}V	0.46 ± 0.07	5.78 ± 0.88	(15-29 MeV) ^{b)} 16.32	0.03
^{52}Cr	1.70 ± 0.22 ^{a)}	21.36 ± 2.76 ^{a)}	(15-29 MeV) ^{c)} 19	0.09

^{a)} The $(\gamma, p_0 + p_1)$ cross section.

^{b)} Ref. ¹⁾.

^{c)} Ref. ²⁴⁾.

TABLE 3

Coefficients obtained by fitting a series of Legendre polynomials $W(\theta) = 1 + A_1 P_1(\cos \theta) + A_2 P_2(\cos \theta)$

	E_e (MeV)	E_e (MeV)	A_1	A_2
^{51}V	17.0	15.4-16.5	0.21 ± 0.05	0.33 ± 0.09
	18.0	16.4-17.5	0.33 ± 0.04	0.33 ± 0.06
	19.0	17.4-18.5	0.28 ± 0.06	0.25 ± 0.11
	21.0	19.4-20.5	0.21 ± 0.07	0.21 ± 0.13
	22.0	20.4-21.5	0.51 ± 0.08	-0.11 ± 0.13
^{52}Cr	21.4	20.5-21.0	0.06 ± 0.07	0.05 ± 0.11

The range of the excitation energy E_x is also indicated.

(over)

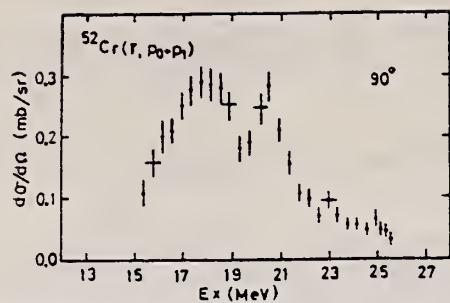


Fig. 3. The differential cross section at 90° for the $^{52}\text{Cr}(\gamma, p_0 + p_1)^{51}\text{V}$ reaction.

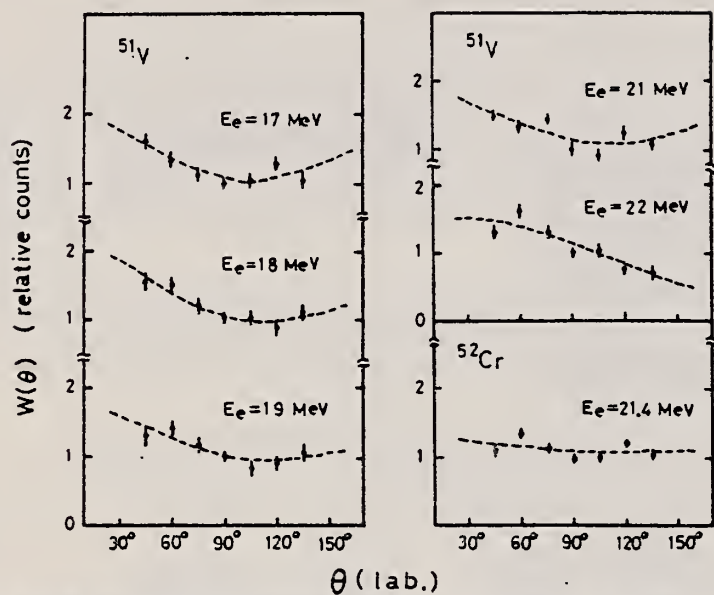


Fig. 6. The angular distributions of protons from the $^{51}\text{V}(e, p_0)^{50}\text{Ti}$ and $^{52}\text{Cr}(e, p_0 + p_1)^{51}\text{V}$ reactions. The dashed curves are the results fitted with the sum of Legendre polynomials, $W(\theta) = 1 + A_1 P_1(\cos \theta) + A_2 P_2(\cos \theta)$.

REF. J. Ahlert M. Schumacher
Z. Phys. A301, 75 (1981)

ELEM. SYM.	A	Z
Cr	52	24

METHOD	REF. NO.	
	81 Ah 6	hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	1	D	1	NAI-D		100
		(1.434)		(1.434)			

A resonance fluorescence self-absorption experiment has been carried out for the 1.434 MeV first excited state in ^{52}Cr , using gaseous $^{52}\text{MnI}_2$ as source for the exciting gamma radiation. The $B(E2, 0_1^+ \rightarrow 2_1^+) = (687 \pm 13) e^2 \text{fm}^4$ is in agreement with the most recent Coulomb excitation and inelastic electron scattering experiments yielding $(660 \pm 30) e^2 \text{fm}^4$ and $(634 \pm 39) e^2 \text{fm}^4$, respectively, and disagrees with former electron scattering experiments.

B(EL), LEVEL 1.434 MEV

Table 1. Experimental results of self-absorption experiment

N_{Cr}, N_{I_2}	0.7594 ± 0.0041
β	1.0142 ± 0.0007
$\mu(\Gamma_0)$	0.7488 ± 0.0041
I_0	$(673 \pm 13) \mu\text{eV}$
τ	$(0.979 \pm 0.019) \text{ps}$
$B(E2)$	$(687 \pm 13) e^2 \text{fm}^4$

Table 2. Comparison of present and previous $B(E2)$ for the 1.434 MeV level in ^{52}Cr

Experiment	Ref.	$B(E2, 0_1^+ \rightarrow 2_1^+) e^2 \text{fm}^4$
Coul. excitation		
Ad 1960	7	620 ± 150
Mc Gow 1962	8	720 ± 90
Sim 1965	9	480 ± 20
Tow 1975	10	660 ± 30
electron scatt.		
Bel 1964	11	520 ± 4
Pet 1971	12	430 ± 70^a
		710 ± 90^b
Lig 1976	13	634 ± 39
DSAM		
Spr 1971	14	680 ± 200
nucl. res. fluor.		
Of 1959	15	341 ± 210
Bo 1964	16	610 ± 170
present work		687 ± 13

Ref. 64 Be 3

Ref. 76 Li 5

Ref. 64 Bo 1

^a Microscopic model ^b Macroscopic model

REF. U.E.P. Berg, D. Ruck, K. Ackermann, K. Bangert, C. Blasing,
K. Kobras, W. Naatz, R.K.M. Schneider, R. Stock, K. Wienhard
Phys. Lett. 103B, 301 (1981)

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.		hg
81 Be 9		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$ G.G	SPC	7 - 10	C	20	SCD-D		90

Nuclear resonance fluorescence experiments with polarized bremsstrahlung were performed to search for magnetic dipole strength. Previous interpretations that states at 7730, 7896 and 9787 keV in ^{52}Cr are due to M1 excitations can not be confirmed. These transitions are unexpectedly strong E1 excitations, exceeding 1 m Weisskopf unit in strength. The remaining identified M1 strength of $\Sigma B(M1)^\dagger = 2.5 \pm 0.7 \mu_N^2$ is in agreement with the observation of missing M1 strength in heavy nuclei.

COH BREM

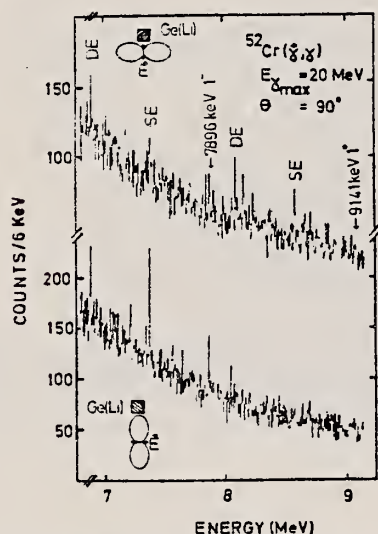


Fig. 1. Parts of the $^{52}\text{Cr}(\gamma, \gamma)$ spectra from photon scattering of linearly polarized bremsstrahlung. In the upper part the electric field vector E of the incoming photon was parallel and in the lower part perpendicular to the scattering plane as shown in the insert.

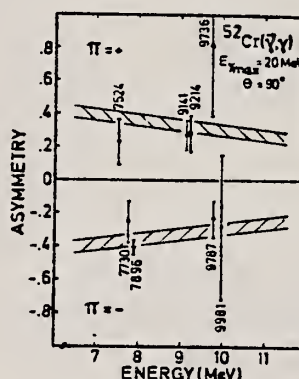


Fig. 2. Asymmetries for different ground-state dipole transitions in ^{52}Cr . The numbers at the error bars are the corresponding excitation energies in keV. The hatched bands were determined with help of the $^2\text{H}(\gamma, p)$ reaction and show the expected asymmetries for even parity (upper part) and odd parity (lower part) excitation.

REF. T.J. Bowles, R.J. Holt, H.E. Jackson, R.M. Laszewski, R.D. McKeown,
A.M. Nathan, J.R. Specht
Phys. Rev. C24, 1940 (1981)

ELEM. SYM.	A	Z
Cr	52	24

METHOD	REF. NO.
	81 Bo 5

hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, G	ABX	15-23	D	15-23	NAI-D		90

Quasimonochromatic photons have been used to measure elastic and inelastic photon scattering cross sections in the giant dipole resonance region of ^{52}Cr , Fe, ^{60}Ni , ^{92}Mo , and ^{96}Mo in an experiment in which the elastic and inelastic scattering are resolved. The elastic scattering cross sections show clear evidence for isospin splitting of the giant dipole resonance. The inelastic scattering to low-lying vibrational levels, which is a measure of the coupling between the giant dipole resonance and collective surface vibrations, is in qualitative agreement with the predictions of the dynamic collective model. However, when examined in detail, this model does not provide an adequate description of the scattering data.

NUCLEAR REACTIONS ^{52}Cr , Fe, ^{60}Ni , $^{92,96}\text{Mo}$ (γ, γ'), $14 \leq E_\gamma \leq 22$ MeV; measured E_γ , $E_{\gamma'}$, $d\sigma/d\Omega$ for γ_0, γ_1 . Compared to DCM predictions. Tagged photons.

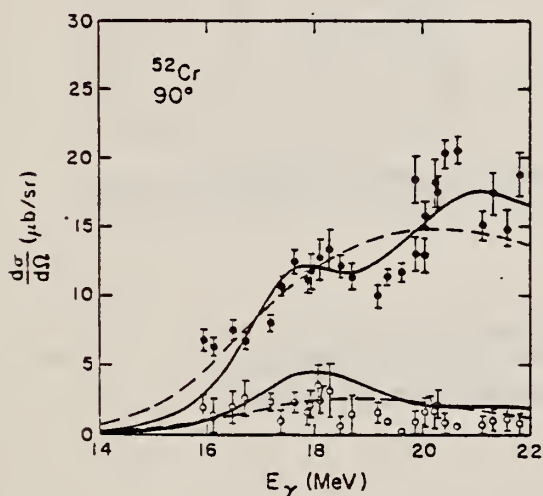


FIG. 8. Elastic (closed circles) and inelastic (open circles) scattering cross sections at $\theta = 90^\circ$ for ^{52}Cr . The error bars represent statistical uncertainties only. The solid (dashed) lines are DCM calculations for the elastic and inelastic cross sections including (not including) the effect of isospin splitting.

REF. B.S. Ishkhanov, Yu.A. Novikov, E.S. Omarov, I.M. Piskarev
Izv. Akad. Nauk SSSR 45, 147 (1981)
Bull. Acad. Sci. 45, 129 (1981)

ELEM. SYM.	A	Z
Cr	52	24
REF. NO.		hg
81 Is 5		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G,G	ABX	5-17	C	6-17	NAI-D		90

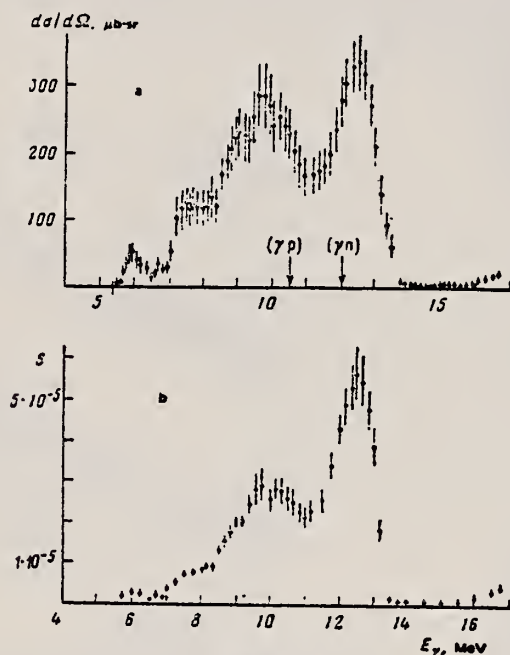


Fig. 2

Fig. 2. a) Cross section for the elastic scattering of protons by a ^{52}Cr nucleus. The arrows denote the thresholds of the (γn) - and (γp) -reactions; b) photon strength function for the ^{52}Cr nucleus, as calculated from the elastic-scattering cross section.

Table 2
Integral Cross Sections for
Scattering of Protons by an ^{52}Cr
Nucleus

Position of maximum, MeV	Integral cross section, MeV·mb
6.0±0.1	0.50±0.15
7.4±0.2	0.9±0.2
9.7±0.2	5.0±0.5
12.5±0.2	5.0±0.5

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G,NG	ABX	12-32	C	10-32	SCD-D		135
G,PG	ABX	10-32	C	10-32	SCD-D		135

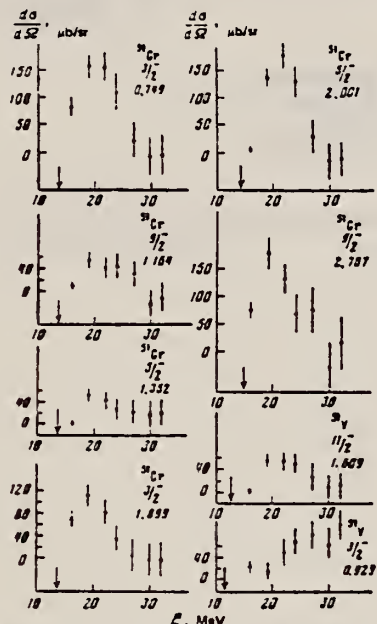


TABLE I. Levels populated in the $^{52}\text{Cr}(\gamma, X\gamma)$ reaction.

Excitation energy, MeV (Ref. 1)	J ^π (Ref. 1)	Integrated cross section, MeV · mb	Final nucleus
0.749	3/2 ⁻	19±2	^{51}Cr
0.777	3/2 ⁻	6±2	
1.164	3/2 ⁻	6±2	
1.352	3/2 ⁻	6±2	
1.557	3/2 ⁻	10±2	
1.899	3/2 ⁻	17±2	
2.001	3/2 ⁻	20±3	
2.767	3/2 ⁻	16±2	^{51}V
3.282	-		
0.320	3/2 ⁻	13±3	
0.929	3/2 ⁻	12±2	
1.608	11/2 ⁻	7±2	

FIG. 1. Differential cross sections for excitation of ^{51}Cr and ^{51}V levels in the $^{52}\text{Cr}(\gamma, X\gamma)$ reaction.

REF. G. Eulenberg, D.I. Sober, W. Steffen, H.-D. Gräf, G. Kuchler,
A. Richter, E. Spamer, B.C. Metsch, W. Knüpfer
Phys. Lett. 116B, 113 (1982)

ELEM. SYM.	A	Z
Cr	52	24

METHOD	REF. NO.	
	82 Eu 1	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,e'/	ABX	8-12	D	30-58	MAG-D		DST

M1 STRENGTH

Following the recent discovery of a very strong magnetic dipole transition in ^{48}Ca to a state at 10.23 MeV in high-resolution inelastic electron scattering, results of a detailed search for M1 strength in the other $N = 28$ isotones ^{50}Ti , ^{52}Cr and ^{54}Fe are described. The M1 strength found in the investigated region of excitation energy $E_x \approx 7-12$ MeV is very fragmented and considerably quenched in comparison to predictions of shell model calculations in a model space that includes up to $2p-2h$ excitations.

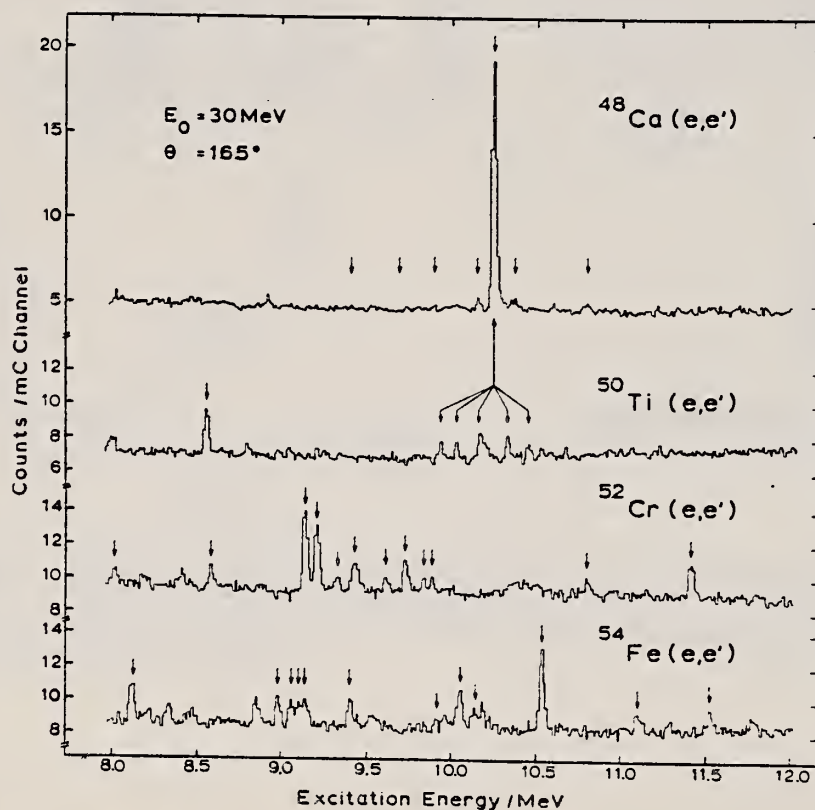


Fig. 1. High-resolution inelastic electron scattering spectra of the $N = 28$ isotones all measured at $E_0 = 30$ MeV and at $\theta = 165^\circ$. The strongest magnetic dipole transitions are indicated by arrows.

(OVER)

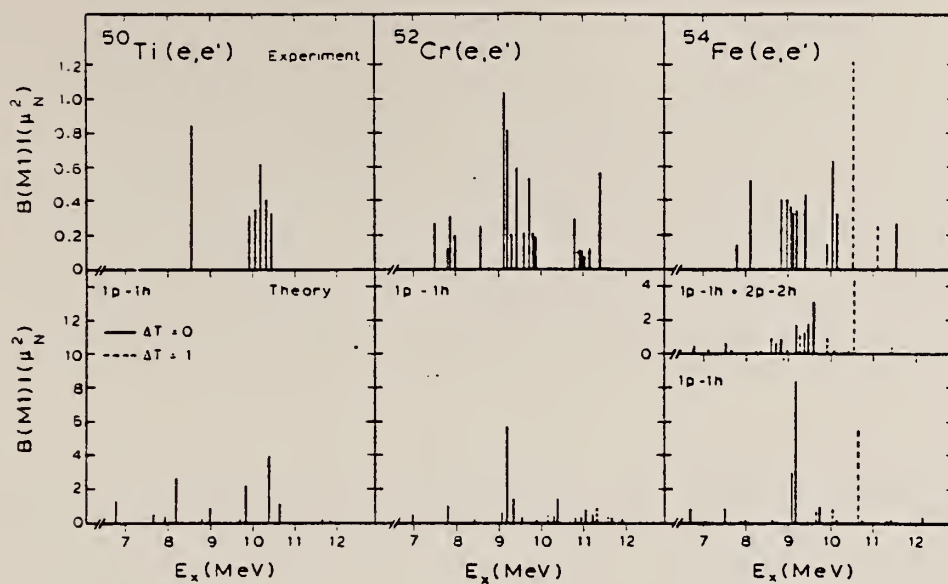


Fig. 3. Comparison of experimental and calculated M1 strength distributions for ^{50}Ti , ^{52}Cr and ^{54}Fe . Note the scale difference. For details, see the main text.

CR
A=53

CR
A=53

CR
A=53

METHOD

Betatron; neutron threshold; ion chamber

REF. NO.

60 Ge 3

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NØX	THR	C	THR	BF3-I		4 PI

THRESHOLD

TABLE I. Summary and comparison of neutron separation energies inferred from present threshold measurements with values predicted from mass data and reaction energies. All energies are expressed in the center-of-mass system in Mev.

Reaction	No. runs	Present results	Other results	Method	Reference
$\text{Cr}^{52}(\gamma, n)\text{Cr}^{51}$	1	7.92 ± 0.06	7.946 ± 0.007 7.943 ± 0.004	$\text{Cr}^{52}(d, p)\text{Cr}^{51}$ mass data	i g

^a C. F. Giese and J. L. Benson, Phys. Rev. 110, 712 (1958).

^b P. M. Endt et al., Phys. Rev. 105, 1002 (1957).

^c M. Mazari, W. W. Buechner, and A. Sperduto, Phys. Rev. 112, 1691 (1958).

REF. E. C. Booth, B. Chasan and K. A. Wright
Nuc1. Phys. 57, 403-420 (1964)

ELEM. SYM.	A	Z
Cr	53	24
REF. NO.		
64 Bo 1		NVB

METHOD					REF. NO.		
					64 Bo 1	NVB	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G.G	LFT	1-3	C	1 - 3	NAT-D		100
		(0.5 - 3.0)		(0.5 - 3.0)			

ABI

TABLE I
Cases of observed resonance fluorescence

Nucleus multipol.	State (MeV)	Spin	Γ_0/Γ	$T(gw\Gamma_0^2/\Gamma^2)^{-1}$ (sec).	Mean lifetime T BCW (sec)	Mean lifetime T other (sec)	Ref.	Γ_0/Γ_w BCW
Cr ⁵³	0.00	$\frac{3}{2}^-$						
M1 ^a	2.32	$\frac{1}{2}^-$	(1)	$6.2 \pm 2 \times 10^{-15}$	$3.1 \pm 1 \times 10^{-15}$			0.9
Mn ⁵⁵	0.00	$\frac{3}{2}^-$						
M1 ^a	1.53	$\frac{3}{2}$	0.9	$27 \pm 8 \times 10^{-14}$	$15 \pm 4 \times 10^{-14}$			5×10^{-3}
[M1] ^a	1.88	$[\frac{3}{2}^-]$	0.82	$23 \pm 7 \times 10^{-15}$	$15 \pm 5 \times 10^{-15} g W$			0.4
[M1] ^a	2.20	$[\frac{3}{2}^-]$	?	$28^{+15}_{-11} \times 10^{-15}$				$0.16 \Gamma/\Gamma_0$
[M1] ^a	2.56	$[\frac{3}{2}^-]$	?	$17^{+15}_{-7} \times 10^{-15}$				$0.18 \Gamma/\Gamma_0$

REF.

Y. Oka, T. Kato, K. Nomura, T. Saito, Hui-Tuh Tsai
Bull. Chem. Soc. Japan 41, 380 (1968)

ELEM. SYM.

A

Z

Cr

53

24.

METHOD

REF. NO.

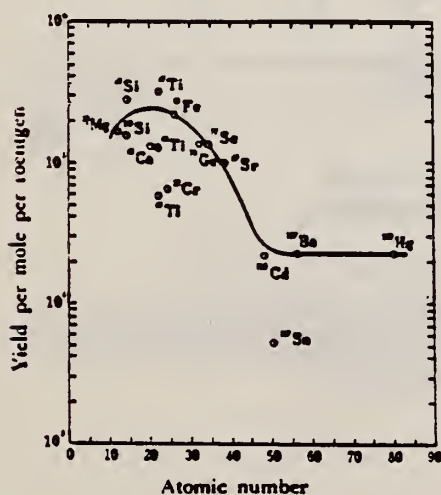
68 Ok 3

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	ABY	THR-20	C	20	ACT-I		4PI

TABLE I. SUMMARY OF DATA ON (γ, p) REACTIONS WITH 20 MeV BREMSSTRAHLUNG

Nuclide		S_p (MeV)	Observed γ -ray			Yield determined	
Parent (Natural abundance, %)	Residual (Half-life)		Energy (MeV)	Branching ratio (%)	Type of multipole transition	$\mu\text{Ci/mg}^a$	Yield/mol·R
^{24}Mg (10.11)	^{24}Na (15 hr)	12.06	1.37	100	E2	1.48×10^{-1}	1.7×10^6
^{28}Si (4.71)	^{28}Al (2.27 min)	12.33	1.78	100	E2	1.91	2.8×10^6
^{28}Si (3.12)	^{28}Al (6.56 min)	13.59	1.28	93.8	E2+M1	6.51×10^{-1}	1.5×10^6
^{40}Ca (2.06)	^{40}K (22.4 hr)	12.17	0.374	85	E2+M1	7.86×10^{-1}	1.3×10^6
^{48}Ti (7.32)	^{48}Sc (84.1 d)	10.47	0.887	100	E2	7.11×10^{-1}	3.1×10^6
^{48}Ti (73.99)	^{48}Sc (3.4 d)	11.44	0.160	100	E2+M1	6.83×10^{-1}	1.2×10^6
^{48}Ti (5.46)	^{48}Sc (1.8 d)	11.35	1.31	100	E2	4.40×10^{-1}	5.8×10^6
^{51}Cr (9.55)	^{51}V (3.8 min)	11.15	1.43	100	E2	5.01×10^{-1}	6.6×10^6
^{54}Fe (2.17)	^{54}Mn (2.58 hr)	10.57	1.81	23.5	E2+M1	8.10×10^{-1}	2.1×10^6
^{72}Ge (36.74)	^{72}Ga (4.8 hr)	10.92	0.295	97	(E2)	3.70×10^{-1}	1.3×10^6
^{76}Se (7.58)	^{76}As (26.5 hr)	9.61	0.559	41	E2	1.48×10^{-1}	1.3×10^6
^{87}Sr (7.02)	^{87}Rb (19 d)	9.41	1.08	9	E2	5.15×10^{-1}	9.9×10^6
^{112}Cd (12.26)	^{112}Ag (3.2 hr)	9.74	1.39	35	E2	1.91×10^{-1}	2.1×10^6
^{117}Sn (7.57)	^{117}In (54 min)	9.58	1.27	84	E2	9.80×10^{-1}	6.9×10^6
^{137}Ba (11.32)	^{137}Cs (13 d)	8.67	0.830	100	E2	1.68×10^{-1}	2.2×10^6
^{199}Hg (16.84)	^{199}Au (2.7 d)	7.27	0.412	100	E2	8.43×10^{-1}	2.2×10^6

a) The value corrected at the end of 1 hr irradiation (9.4×10^6 R/min).Fig. 2. The yield curve for the (γ, p) reaction with 20 MeV bremsstrahlung.

METHOD

REF. NO.

[Page 1 of 3]

71 Ba 2

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	9-12	C	9,12	TOF-D		135
		(9.2-11.5)					

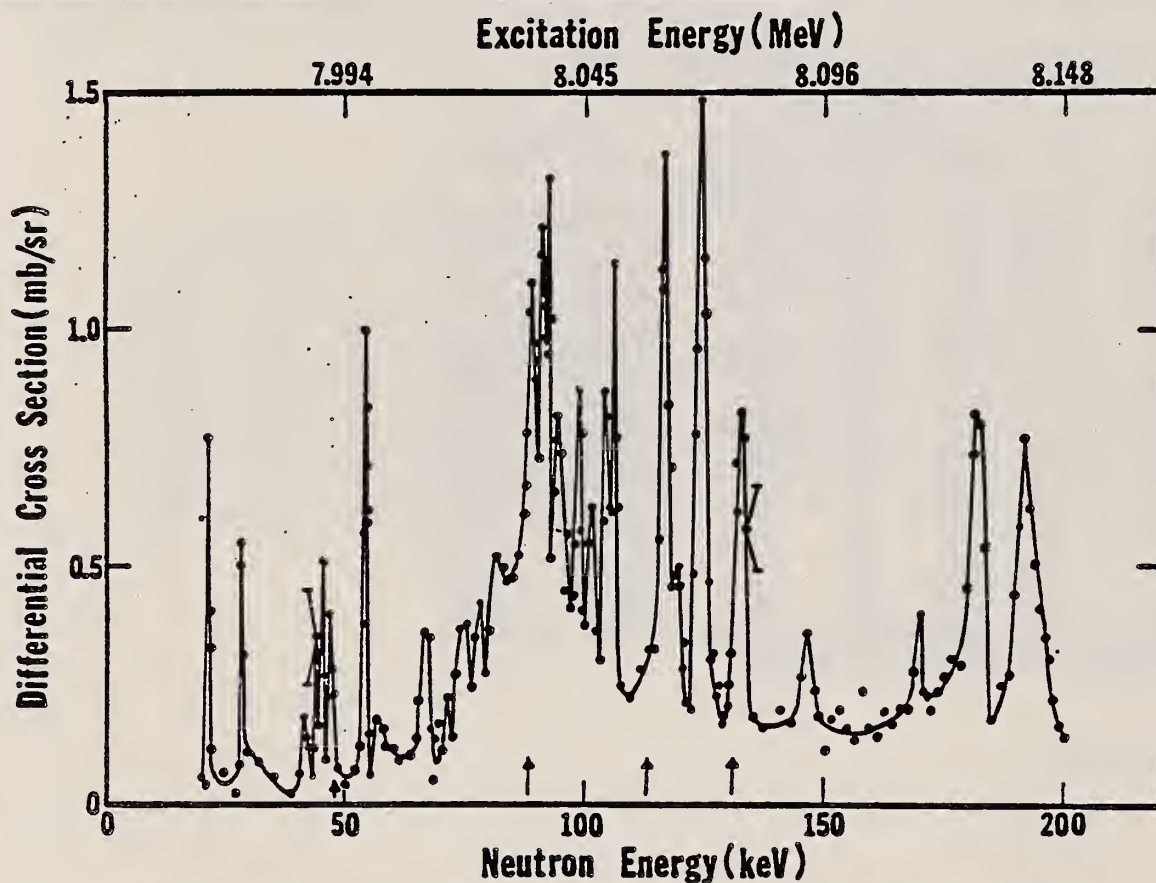


FIG. 12. The 135° differential threshold photoneutron cross section for ^{52}Cr , at low energies (see caption to Fig. 4). The arrows below the data indicate the positions of $J^\pi = \frac{1}{2}^+$ states obtained from neutron total cross-section measurements on ^{52}Cr .

FIG. 4. The 135° differential threshold photoneutron cross section for ^{207}Pb at low energies versus the energy of the emitted neutron (lower scale) and the excitation energy (upper scale). The arrows indicate peaks which decay to excited states of the residual nucleus (ES), or peaks owing to contaminating isotopes in the photoneutron sample. The inset shows the $^{207}\text{Pb}(\gamma, n)$ cross section averaged with a square 40-keV wide smoothing function.

Also see:

R. J. Baglan et al.
Phys. Rev. C3, 2475
(1971)

[over]

Nucleus	E_L (keV)	E_{ex} (MeV)	$g_\gamma \Gamma_{\gamma 0} \Gamma_n / \Gamma$ (eV)	GS or ES	J^π	$\Gamma_{\gamma 0}$ (eV)	E_n (keV) (This work)	E_n (keV) from neutron- induced reactions (Ref. a) (Ref. b) (Ref. c)		
⁵³ Cr	543	11.761	0.97	GS			568			
	576	11.795	0.34				602			
	594	11.813	1.89	GS			621			
	627	11.847	2.30	GS			656			
	705	11.927	0.37				737			
	21.4	7.964	0.013				23.0			22.9
	28.3	7.971	0.031				30.3			
	44.4	7.988	0.022				47.2			
	45.5	7.989	0.034				48.4			
	47.1	7.991	0.042		$\frac{1}{2}^+ a, c$	0.17	50.1	51		48.3
	54.5	7.998	0.084	GS			57.8			50.2
	67.2	8.011	0.049				71.1			57.8
	89.0	8.034	0.38				94.0			
	91.0	8.036	0.17				96.1			
	92.7	8.037	0.057				97.9			
	94.4	8.039	0.25				99.6			
	98.6	8.044	0.15				104			
	102	8.047	0.11				108			107
	104	8.049	0.13				110			111
	106	8.051	0.10				112			113
	117	8.062	0.31	GS			123			123.2
	124	8.070	0.34	GS			131	130		132
	132	8.078	0.20	GS			139			
	147	8.093	0.065				155			155
	170	8.117	0.054				179			
	182	8.129	0.31	GS			191			
	191	8.138	0.35	GS			201	199		
	212	8.160	0.084				223	224		
	224	8.172	0.40	GS	$\frac{1}{2}^+ a$	1.6	235	235		
	234	8.182	0.07				246	246		
	272	8.221	0.18	GS	$\frac{1}{2}^+ a, c$	0.72	285	281		285.4
	292	8.242	0.58	GS			306			
	315	8.266	0.74	GS	$\frac{1}{2}^+ a, c$	3.0	330	326		331.1
	333	8.284	0.60	GS			349	349		
	347	8.298	0.32		$\frac{1}{2}^+ a$	1.3	364	364		
	371	8.323	0.20				389			
	389	8.341	0.09		$\frac{1}{2}^+ a$	0.36	408	401		
	404	8.357	0.06		$\frac{1}{2}^+ a$	0.24	423	418		
	422	8.375	0.24				443	442		
	440	8.394	0.11				461			
	454	8.408	0.54	GS			475			
	480	8.434	0.68	GS			502			
	510	8.465	0.19	GS	$\frac{1}{2}^+ a$	0.76	533	530		
	519	8.474	0.20	GS			543			

^aSee Ref. 17.^bSee R. W. Hockenbury, Z. M. Bartolome, J. R. Tatarczuk, W. R. Moyer, and R. C. Block, Phys. Rev. 173, 1746 (1969).^cSee Ref. 19.¹⁷C.D. Bowman, E.G. Bilpuch, and H.W. Newson, Ann. Phys. (N.Y.) 17, 319 (1962).^bSee R.W. Hockenbury, Z.M. Bartolome, J.R. Tatarczuk, W.R. Moyer, and R.C. Block, Phys. Rev. 173, 1746 (1969).¹⁹R.G. Steiglitz, Ph.D. thesis, Rensselaer Polytechnic Institute, 1970 (unpub.)

REF. R. J. Baglan, C. D. Bowman and B. L. Berman
Phys. Rev. C3, 672 (1971)

ELEM. SYM.	A	Z
Cr	53	24

METHOD

(Page 3 of 3)

REF. NO.	
71 Ba 2	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

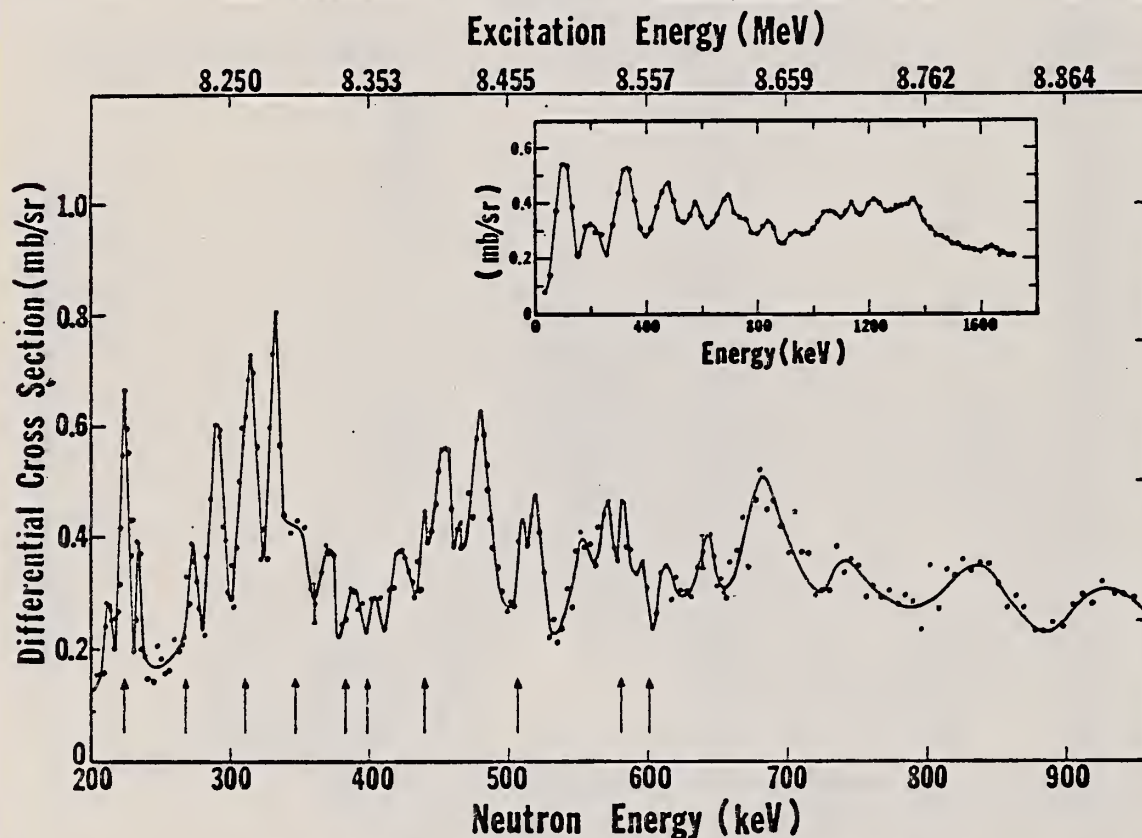


FIG. 13. The 135° differential threshold photoneutron cross section for ^{53}Cr , at high energies (see caption to Fig. 4). The arrows below the data indicate the positions of $J^\pi = \frac{1}{2}^+$ states obtained from neutron total cross-section measurements on ^{53}Cr .

METHOD

REF. NO.	hmg
71 Ja 1	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	RLX	7-9	C	7-9	TOF-D		DST
		(7.9 - 9.1)		(7.9-9.1)			

No evidence found near threshold for doorway states.

TABLE II. Energies and parameters for resonances in the reaction $^{53}\text{Cr}(\gamma, n)$. The $\pm 20\%$ error in the quantity $\Gamma_{\gamma 0} \Gamma_n / \Gamma$ for all resonances is due mainly to the uncertainty in the absolute normalization of the data. The energies given in column 2 are calculated from those of column 1 by applying a correction for recoil effects. For unassigned levels, column 4 gives $g \Gamma_{\gamma 0} \Gamma_n / \Gamma$.

TABLE I. Angular momentum assignments for resonances in the reaction $^{53}\text{Cr}(\gamma, n)$. Excitation of levels is assumed to take place only by absorption of dipole radiation.

$E_n(\gamma, n)$ (keV)	$\frac{d\sigma(90^\circ)/d\Omega}{d\sigma(135^\circ)/d\Omega}$	J^π	$E_n(\gamma, n)$ (keV)	$\frac{d\sigma(90^\circ)/d\Omega}{d\sigma(135^\circ)/d\Omega}$	J^π
47.7	s wave	$\frac{1}{2}^+$	196	0.78 ± 0.08	$\frac{1}{2}^-$
92	s wave	$\frac{1}{2}^+$	226	s wave	$\frac{1}{2}^+$
101	0.54 ± 0.06	$\frac{1}{2}^-$	233	1.10 ± 0.06	$\frac{1}{2}^-$
105	0.69 ± 0.06	$\frac{1}{2}^-$	241	0.72 ± 0.08	$\frac{1}{2}^-$
107	0.70 ± 0.06	$\frac{1}{2}^-$	274	0.66 ± 0.07	$\frac{1}{2}^-$
117	s wave	$\frac{1}{2}^+$	294	1.09 ± 0.04	$\frac{1}{2}^-$
125	0.53 ± 0.03	$\frac{1}{2}^-$	315	s wave	$\frac{1}{2}^+$
133	0.66 ± 0.04	$\frac{1}{2}^-$	317	0.71 ± 0.03	$\frac{1}{2}^-$
146	1.01 ± 0.10	$\frac{1}{2}^-$	333	1.01 ± 0.04	$\frac{1}{2}^-$
182	1.15 ± 0.03	$\frac{1}{2}^-$	350	0.68 ± 0.06	$\frac{1}{2}^-$
193	1.10 ± 0.03	$\frac{1}{2}^-$	373	1.06 ± 0.11	$\frac{1}{2}^-$

$E_n(\gamma, n)$ References 18, 19 (keV)	$E_n(\gamma, n)$ at $\theta = 135^\circ$		$\Gamma_{\gamma 0} \Gamma_n / \Gamma$ (eV)
	Calc. (keV)	Obs. (keV)	
$J = \frac{1}{2}^+$			
50.2 ± 0.3	47.3	47.7	0.179
97.1 ± 0.5	92.0	92.0	1.275
123.2 ± 1.0	117	117	0.930
141.4 ± 1.2	134	...	...
209.4 ± 2.2	228	226	1.315
255.4 ± 2.3	272	...	...
331.1 ± 3.5	316	315	0.184
			Total 3.884
$J = \frac{1}{2}^-$			
155 ± 1.2	147	146	0.234
...	...	182	1.210
...	...	193	1.137
...	...	233	0.408
...	...	294	0.748
...	...	333	1.324
			Total 5.062
$J = \frac{1}{2}^-$			
107 ± 0.6	101	101	0.075
111 ± 0.9	105	105	0.102
113 ± 0.9	107	107	0.143
132 ± 0.9	125	125	0.256
...	...	133	0.193
...	...	196	0.151
...	...	241	0.069
...	...	274	0.077
...	...	317	0.395
...	...	350	0.249
			Total 1.710
Unassigned levels			
22.9 ± 1.0	21.3	21.4	0.026
48.3 ± 0.21	45.4	45.5	0.009
57.8 ± 0.28	54.5	54.6	0.046
...	...	175	0.046
			Total 0.127

(over)

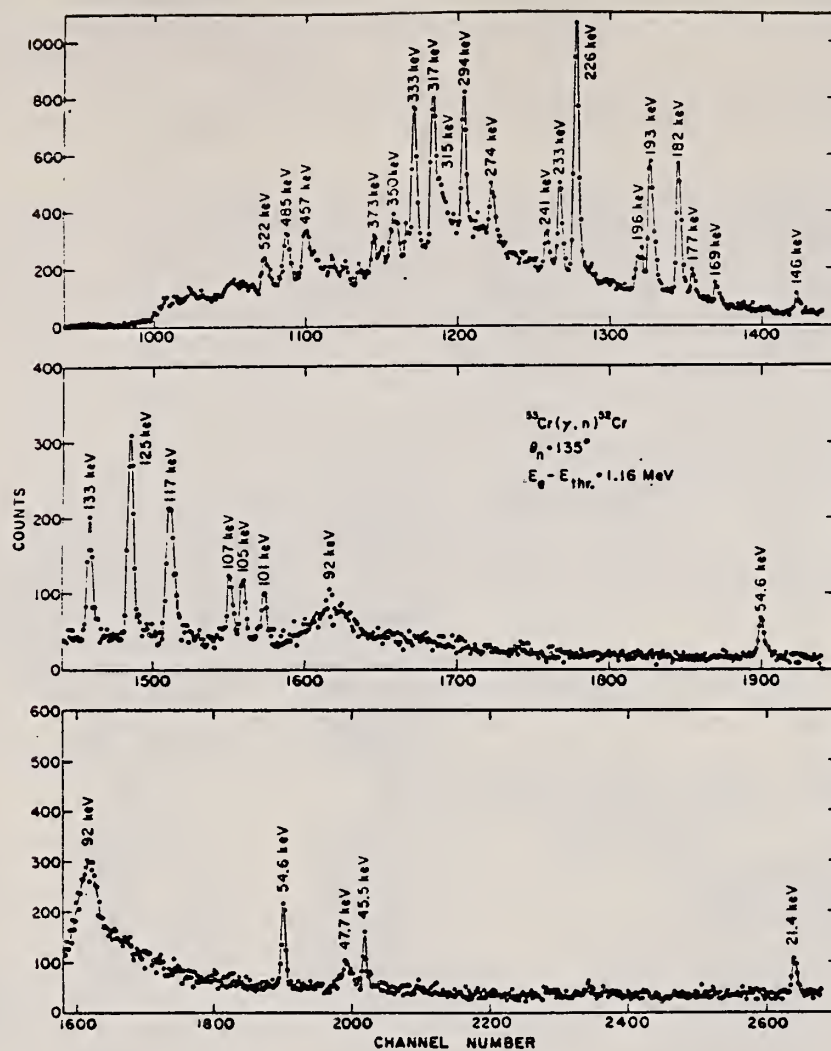


FIG. 4. Photoneutron time-of-flight spectrum for $^{53}\text{Cr}(\gamma, n)$. The flight path was 9 m. In the section for channels 1600 to 2700, each point represents the sum of two adjacent channels.

TABLE VII. Integrated yields and reduced widths for electric and magnetic dipole radiation. Integrated yields are given for all resonances observed, but reduced widths for magnetic dipole transitions are calculated only from yields for p -wave levels above 100-keV neutron energy (see discussion in Sec. IV). The number of resonance widths used to obtain each \bar{k} is given by n . The errors given were calculated by assuming that the individual $\Gamma_{\gamma 0}$'s follow a Porter-Thomas distribution.

Target	J^π	$\sum g \Gamma_{\gamma 0} \Gamma_n / \Gamma$ (eV)	$\sum \Gamma_{\gamma 0} \Gamma_n / \Gamma$ (eV)	n	$10^3 \times$ reduced width Individual average
^{53}Cr	$\frac{1}{2}^+$	0.97	3.88	7	$\bar{k}_{E1} = 1.7^{+1.1}_{-0.5}$
	$\frac{1}{2}^-$	1.27	5.06	6	$\bar{k}_{M1} = 41$
	$\frac{3}{2}^-$	0.86	1.71	10	$\bar{k}_{M1} = 16$
^{51}Fe	$\frac{1}{2}^+$	0.83	1.66	8	$\bar{k}_{E1} = 0.86^{+0.8}_{-0.3}$
	$\frac{1}{2}^-$	0.37	0.74	4	$\bar{k}_{M1} = 9$
	$\frac{3}{2}^-$	0.84	0.84	3	$\bar{k}_{M1} = 10$
^{45}Ni	$\frac{1}{2}^+$	0.37	1.48	11	$\bar{k}_{E1} = 0.96^{+0.42}_{-0.19}$
	$\frac{1}{2}^-$	0.41	1.65	5	$\bar{k}_{M1} = 27$
	$\frac{3}{2}^-$	0.54	1.07	3	$\bar{k}_{M1} = 12$

REF.

B. S. Ratner
ZhETF Pis. Red. 13, 628 (1971)
JETP Letters 13, 447 (1971)

ELEM. SYM.

A

Z

Cr

53

24

METHOD

REF. NO.

71 Ra 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	RLY	11-14	C	11-14	ACT-I		4PI

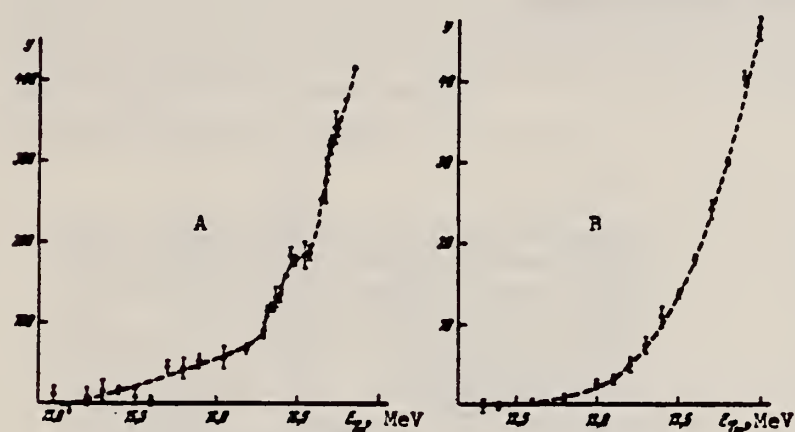


Fig. 1. Yield of reactions
 $\text{Ni}^{64}(\gamma, p)\text{Co}^{63}$ (A) and
 $\text{Cr}^{53}(\gamma, p)\text{U}^{52}$ (B) near the
threshold, averaged over $E_{\gamma m}$
in the interval 10 - 100 keV

REF. B. S. Ratner
Yad. Fiz. 21, 1147 (1975)
Sov. J. Nucl. Phys. 21, 590 (1976)

ELEM. SYM.	A	Z
Cr	53	24

METHOD

REF. NO.	
75 Ra 2	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, P	RLY	11- 14	C	12- 14	ACT-I		4PI

The yields of (γ , p) reactions on ^{62}Ni , ^{64}Ni , and ^{53}Cr are studied in ranges of $E_{\gamma\text{max}}$ near the respective thresholds. Considerable differences are found between the curve shapes, yields, and observed thresholds for the Ni isotopes and ^{53}Cr .

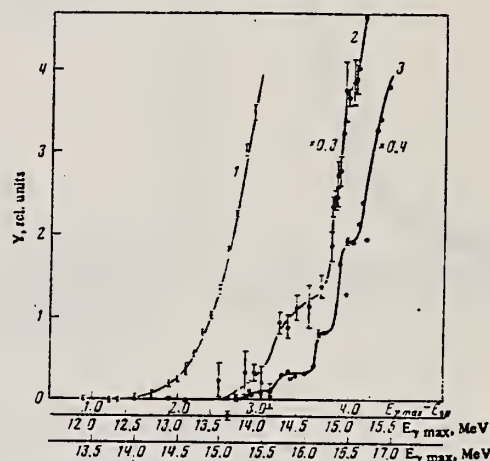


FIG. 3. Yields of the reactions $^{53}\text{Cr}(\gamma, p)^{52}\text{V}$ (curve 1), $^{64}\text{Ni}(\gamma, p)^{63}\text{Co}$ (curve 2), and $^{62}\text{Ni}(\gamma, p)^{61}\text{Co}$ (curve 3) as functions of $E_{\gamma\text{max}}$. Lowest scale for $^{64}\text{Ni}(\gamma, p)$; middle scale for $^{62}\text{Ni}(\gamma, p)$ and $^{53}\text{Cr}(\gamma, p)$.

REF. V.N. Polishchuk, N.G. Shevchenko, N.G. Afanas'ev, A.A. Khomich,
A.Yu. Buki, B.V. Mazan'ko
Yad. Fiz. 27, 1145 (1978)
Sov. J. Nucl. Phys. 27, 607 (1978)

ELEM. SYM.	A	Z
Cr	53	24

METHOD	REF. NO.	hg
	78 Po 3	hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	0-2	D	90, 120	MAG-D		DST

Inelastic electron scattering has been used to measure the form factors of the 1.43-MeV level in ^{52}Cr and the 0.56-, 1.01-, 1.29-, and 1.97-MeV levels in ^{53}Cr . The measurements were made with an initial electron energy $E_0 = 90, 120, \text{ and } 226 \text{ MeV}$ in the momentum-transfer region $0.85\text{--}1.7 \text{ F}^{-1}$ and $0.74\text{--}1.15 \text{ F}^{-1}$ respectively for ^{52}Cr and ^{53}Cr . For these states reduced transition probabilities $B(E2) \uparrow$ were obtained, respectively $800 \pm 80, 100 \pm 20, 170 \pm 18, 335 \pm 30, \text{ and } 190 \pm 15 \text{ e}^2 \cdot \text{F}^4$. The results obtained are discussed in terms of the excited-core model.

LEV .56, 1.01, 1.29, 1.97

PACS numbers: 25.30.Cg, 27.40.+z, 23.20.Ck

TABLE I. Reduced probabilities for transition from the ground state of the nucleus to excited states for the isotopes $^{52,53}\text{Cr}$.

Nucleus	Transition $J_i \rightarrow J_f$	$E, \text{ MeV}$	Value of $B(E\lambda)/1, \text{ e}^2 \cdot \text{F}^{2\lambda}$									
			Experiment				Theory					
			Our data	[7]	[8]	[9]	[10]				[11]	
							Generalized model		Shell model		[12]	[13]

							$e_n = e$	$e_n = 0$				
^{53}Cr	$1/2^- \rightarrow 1/2^-$	0.56	100 ± 20	115 ± 12	110 ± 20	89	98	50	20	73	59	62.5
	$1/2^- \rightarrow 3/2^-$	1.01	170 ± 10	72 ± 8	70 ± 25	52	113	4	33	53	162	201.3
	$1/2^- \rightarrow 5/2^-$	1.29	335 ± 30	300 ± 40	240 ± 20	138	220	120	230	126	99	244
	$1/2^- \rightarrow 7/2^-$	1.97	190 ± 15				64	55				
	$1/2^- \rightarrow 9/2^-$	2.32					33	50			149	140
			Our data	[7]	[8]	[9]	[10]		[11]			
							$e_n = 0.6$	$e_n = 0.7$	[12]			
^{52}Cr	$0 \rightarrow 2^+$	1.43	810 ± 90	720 ± 90	720	761 ± 30	610	720	940			

¹⁾ Calculation carried out for $M_{22} = 25 \text{ e} \cdot \text{F}^2$ and $\xi = -0.169 \text{ MeV}$, $\eta = -0.0002 \text{ MeV} \cdot \text{e}^{-2} \cdot \text{F}^{-4}$.

²⁾ Calculation carried out for $M_{22} = 25 \text{ e} \cdot \text{F}^2$ and $\xi = -0.125 \text{ MeV}$, $\eta = -0.00055 \text{ MeV} \cdot \text{e}^{-2} \cdot \text{F}^{-4}$.

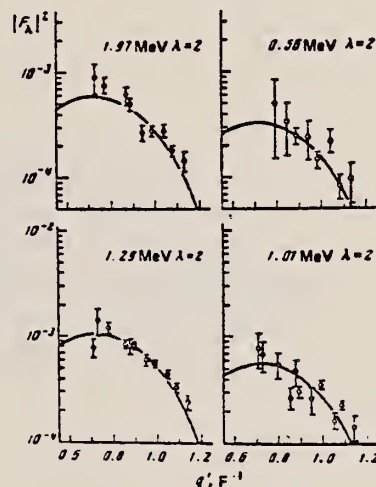


FIG. 1. Form factors of the levels $1/2^-$ (0.56 MeV), $5/2^-$ (1.01 MeV), $7/2^-$ (1.29 MeV), and $5/2^-$ (1.97 MeV) in the nucleus ^{53}Cr . The points are experimental, and the curves are calculated by a phase-shift analysis.

Mn
A=51

MANGANESE
Z=25

Manganese was first recognized as an element by the Swedish chemist Scheele in 1774 while working with the MnO_2 ore pyrolusite. The metal is frequently found in conjunction with iron ores and was named for the magnetic properties exhibited by pyrolusite from the Latin "magnes" or magnet; the German equivalent is "mangan" and the French, "manganese".

Mn
A=51

Mn
A=51

ELEM. SYM.	A	Z
Mn	51	25
REF. NO.	67 Er 1	
	egf	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	NOX	6-7	P	1-2	SCD-D	1-7	DST

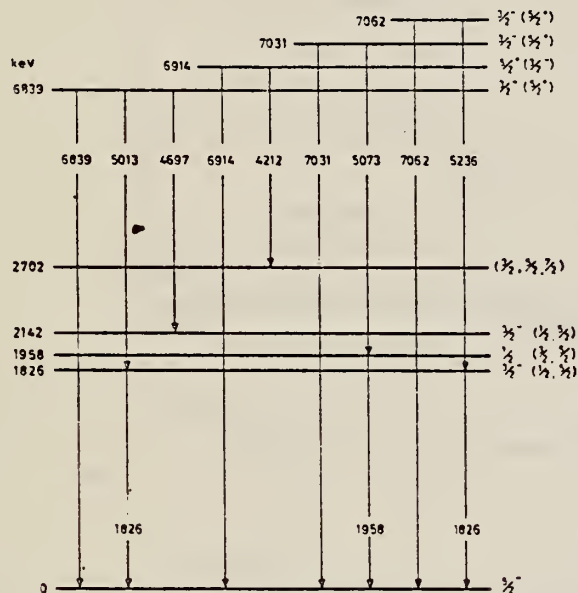


Fig. 1. The level and decay scheme of Mn^{51} from this investigation.

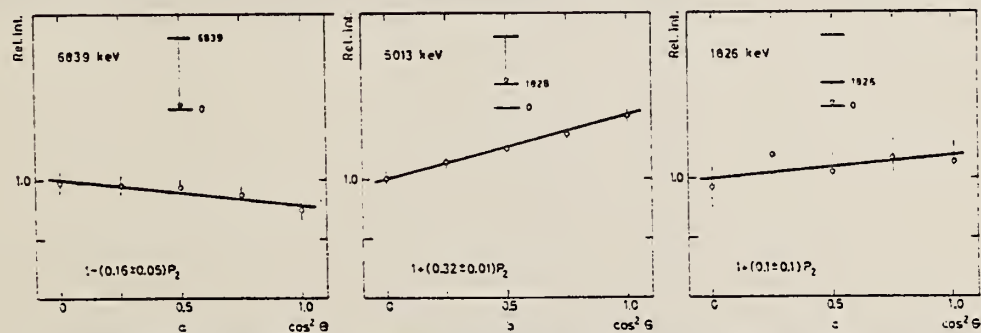


Fig. 2. Angular distributions of the 6839, 5013 and 1826 keV gamma lines as measured at the 1602 keV resonance.

[over]

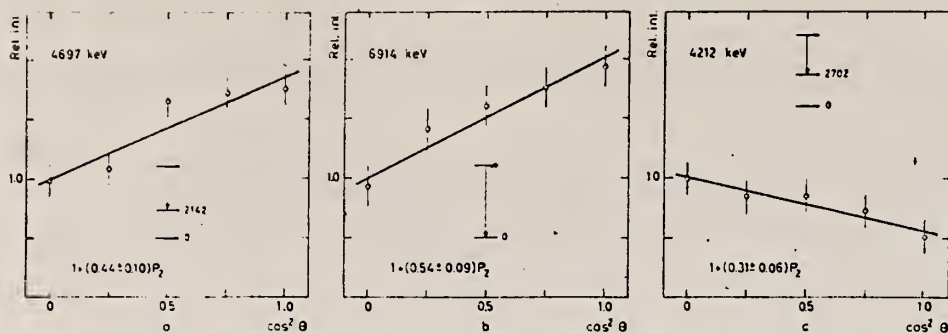


Fig. 3. Angular distributions of the 4697 keV gamma line as measured at the 1602 keV resonance and the 6914 and 4212 keV gamma lines as measured at the 1679 keV resonance.

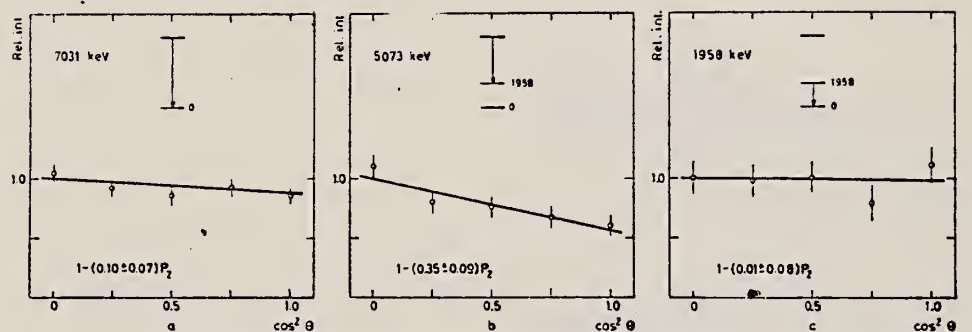


Fig. 4. Angular distributions of the 7031, 5073 and 1958 keV gamma lines as measured at the 1798 keV resonance.

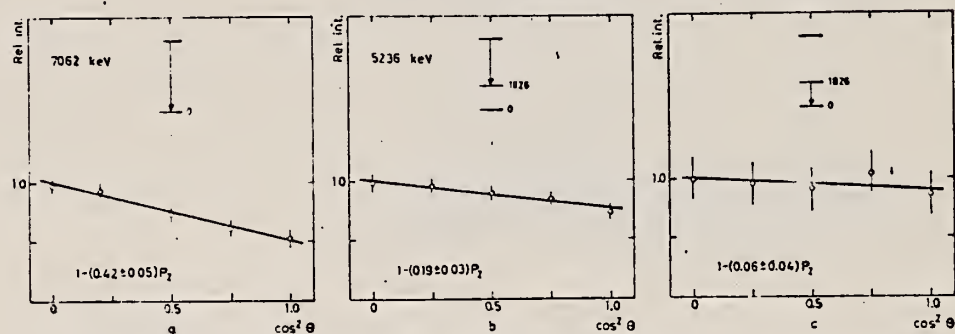


Fig. 5. Angular distributions of the 7062, 5236 and 1826 keV gamma lines as measured at the 1830 keV resonance.

MN
A=53

MN
A=53

MN
A=53

METHOD
3 MeV Van de Graaff

[Page 1 of 2]

REF. NO.
66 Vu 1

JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	RLY	7-9	D	1-2	NAI-D	4-9	90

TABLE I
Resonances in the $^{52}\text{Cr}(p, \gamma)^{53}\text{Mn}$ reaction ^{a, b)}

No. res.	E_p ^{c)} (keV)	E_x ^{d)} (MeV)	$(2J+1)\gamma$ ^{e)} (eV)	E_p (ref. ^{a)}) (keV)	No. res.	E_p (keV)	E_x (MeV)	$(2J+1)\gamma$ (eV)	Remarks
1	1367.5	7.903	0.43	1366	48	1657.2	8.187	0.04	
2	1374.4	7.909	0.03		49	1661.0	8.191	0.06	
3	1382.2	7.917	0.07	1381	50	1662.3	8.192	0.34	
4	1387.5	7.922	1.2	1387	51	1664.0	8.194	0.7	
5	1394.8	7.929	0.8	1394	52	1666.1	8.196	0.5	
6	1405.2	7.940	0.32	1405	53	1667.8	8.197	0.29	
7	1431.5	7.965	0.28	1433	54	1672.8	8.202	0.11	
8	1442.9	7.977	0.7	1444	55	1689.5	8.219	0.6	
9	1444.9	7.979	0.03		56	1695.1	8.224	0.43	
10	1448.4	7.982	0.04		57	1705.1	8.234	0.06	
11	1460.9	7.994	0.09		58	1706.9	8.236	0.05	
12	1472.7	8.006	0.09		59	1717.7	8.246	0.30	
13	1473.5	8.007	0.7		60	1723.6	8.252	2.2	
14	1479.0	8.012	0.12		61	1726.9	8.255	0.14	
15	1483.5	8.017	0.10	Remarks	62	1729.5	8.258	0.40	
16	1493.2	8.026	0.26		63	1735.7	8.264	0.6	
17	1493.9	8.027	0.20		64	1743.9	8.272	0.6	
18	1496.8	8.030	0.30		65	1747.9	8.276	(0.38)	double?
19	1498.5	8.031	0.10		66	1749.4	8.277	0.22	
20	1506.1	8.039	(0.24)	double?	67	1755.2	8.283	0.05	
21	1508.6	8.041	0.03		68	1761.5	8.289	0.09	
22	1514.5	8.047	0.12		69	1767.2	8.295	1.0	
23	1521.2	8.053	0.6		70	1769.1	8.297	0.48	
24	1525.0	8.057	0.42		71	1770.2	8.298	0.08	
25	1528.2	8.060	0.02		72	1771.8	8.299	0.06	
26	1532.9	8.065	0.04		73	1778.6	8.306	1.1	
27	1539.5	8.071	0.29		74	1780.6	8.308	0.49	
28	1544.1	8.076	0.21		75	1784.9	8.312	0.05	
29	1550.0	8.082	0.38		76	1788.2	8.315	0.7	
30	1554.3	8.086	0.13		77	1796.4	8.323	0.14	
31	1555.9	8.088	0.6		78	1797.6	8.325	0.26	
32	1563.3	8.095	0.7		79	1803.1	8.330	1.2	
33	1568.0	8.099	0.12		80	1806.3	8.333	0.05	
34	1569.8	8.101	0.06		81	1811.3	8.338	0.29	
35	1577.3	8.109	0.12		82	1813.0	8.340	0.6	
36	1587.4	8.118	0.15		83	1824.5	8.351	0.5	
37	1590.1	8.121	0.32		84	1825.7	8.352	0.10	
38	1600.5	8.131	0.29		85	1827.8	8.354	0.17	
39	1602.2	8.133	0.23		86	1829.2	8.356	0.8	
40	1603.6	8.134	0.6		87	1833.3	8.360	0.30	
41	1608.5	8.139	1.2		88	1834.3	8.361	0.03	
42	1626.7	8.157	0.7		89	1836.1	8.362	0.33	
43	1632.8	8.163	0.04		90	1841.9	8.368	0.03	
44	1643.5	8.174	0.05		91	1846.8	8.373	0.02	
45	1646.6	8.177	0.7		92	1851.9	8.378	(0.27)	double?
46	1650.7	8.181	0.03		93	1853.5	8.379	0.41	
47	1653.4	8.183	0.14		94	1857.4	8.383	0.07	

^{a)} Not reported are about 30 resonances of which the assignment to the $^{52}\text{Cr}(p, \gamma)^{53}\text{Mn}$ reaction is uncertain; their strength is less than 0.05 eV if they belong to this reaction.

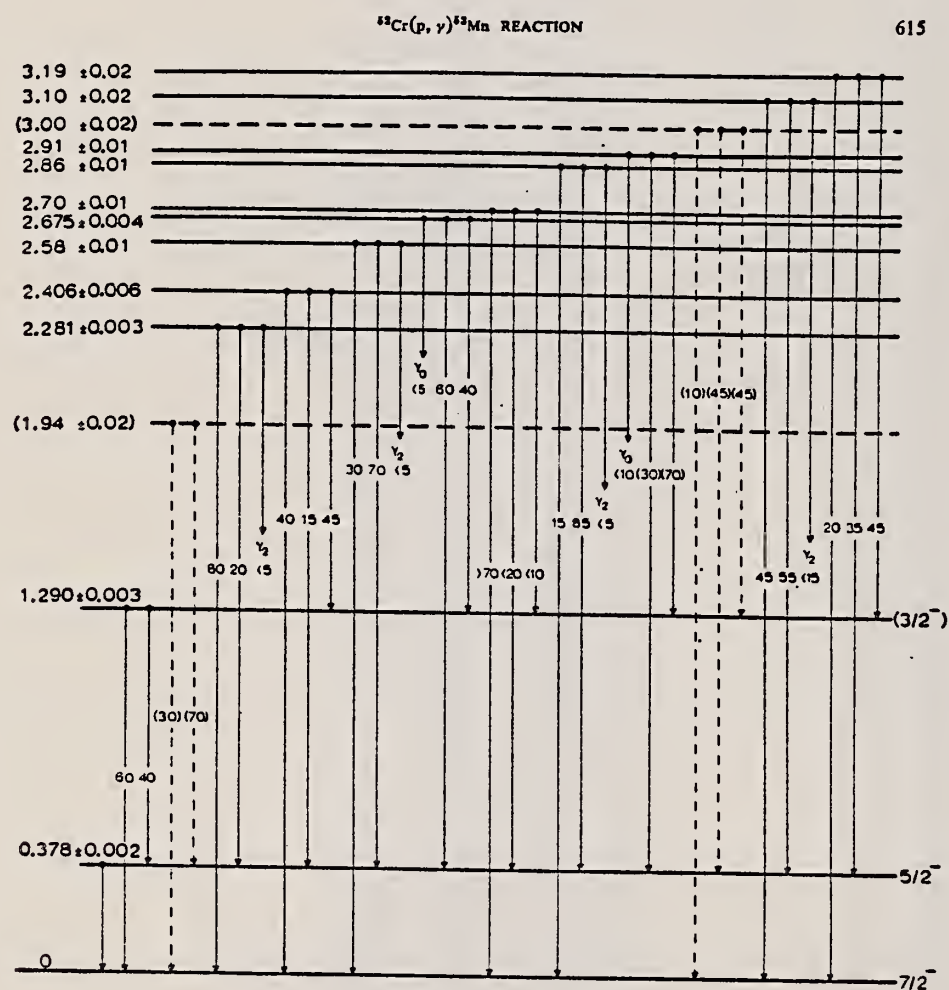
^{b)} For all resonances the natural width is smaller than the experimental resolution of 400 eV.

^{c)} The error in E_p increases from 1.4 keV at $E_p = 1350$ keV to 2.0 keV at $E_p = 2250$ keV.

^{d)} All ± 7 keV.

^{e)} The values of $(2J+1)\Gamma_p\Gamma_\gamma/\Gamma \equiv (2J+1)\gamma$ are considered to be correct within a factor of 2.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	



^{53}Mn

Fig. 15. Level and decay scheme of ^{53}Mn . Transitions between levels with $E_x > 1.30$ MeV were not investigated.

REF.

K. Beckert, H.W. Hersch, D. Grambole, F. Herrmann,
P. Kleinvechter, C. Schneiderait, H. Schobbert, H.J. Thomas
Izv. Akad. Nauk SSSR. Ser. Fiz. 38, 2087 (1974)
Bull. Acad. Sci. USSR Phys. Ser. 38, 63 (1974)

ELEM. SYM.

A

Z

Mn

53

25

METHOD

REF. NO.

74 Be 13

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	SPC	6- 11	D	3- 5	SCD-D		DST

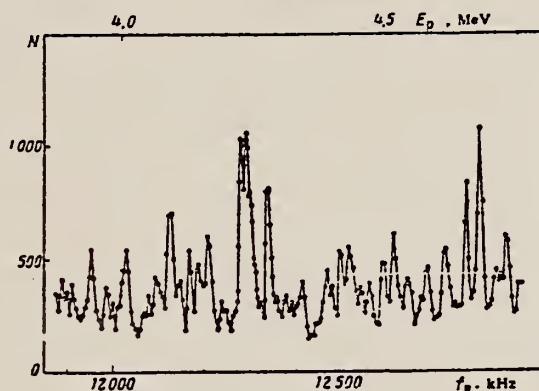


Fig. 1. Excitation function for $^{52}\text{Cr}(p,\gamma)^{53}\text{Mn}$ (measured at 90° to the beam) for $E_\gamma > 7$ MeV (N is the number of counts for 60 μCi).

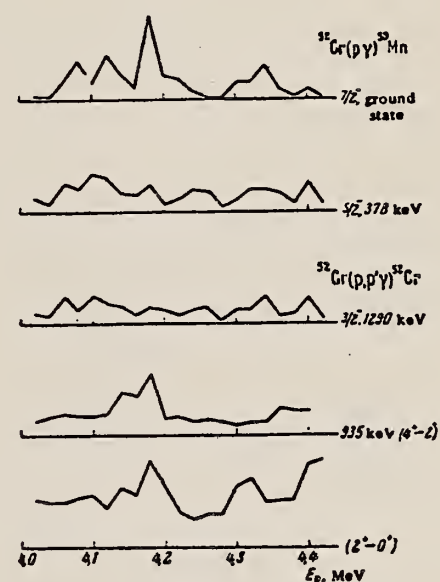


Fig. 2. Differential excitation functions for transitions from the capture level to the first bound states of ^{53}Mn and for transitions accompanying inelastic proton scattering $^{52}\text{Cr}(p,p'\gamma)$.

TABLE 1

Main γ Transitions Observed in the Decay of the Resonance at $E_p = 4183$ keV at 55° to the Beam

Final state E_x , keV	Branching ratio, %	I^π [10]	Final state E_x , keV	Branching ratio, %	I^π [10]
0	42.4	$7/2^-$	2672.0 (2.5)	4.5	$7/2^-$
378.3 (0.5)	13.5	$5/2^-$	2685.9 (1.0)		$3/2^-$
1289.9 (0.7)	6.4	$3/2^-$	2876.9 (1.0)		$5/2^-$
1435 (4)	4.3	$1/2^-$	2942.2 (2.0)		
1620.3 (0.4)	1.8	$5/2^-$	3004.1 (1.0)	0.9	
2274.2 (0.4)	4.5	$7/2^-$	3098.3 (1.0)	2.2	$3/2^-$
2407.0 (1.0)	1.5	$3/2^-$	3198.3 (1.5)	4.3	$5/2^-$
2573.7 (1.0)	5.0	$7/2^-$	3167.5 (2.0)	2.9	

*The relative error in the intensity of the transition to the ground state is about 10%. The corresponding errors for the other transitions are 20-25%.

MN
A=55

MN
A=55

MN
A=55

Ref. E.G. Fuller, E. Hayward
Phys. Rev. 101, 692 (1956)

Elem. Sym.	A	Z
Mn	55	25

Method Betatron; photon scattering; NaI spectrometer

Ref. No.	EH
56 Fu 1	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$Mn^{55}(\gamma, \gamma)$	Bremss. 4-40					Detector at 120° . Cross sections given here are 13% too high due to erroneous $\cos \beta$ factor in denominator of Eq. 5. [See footnote 8 in Phys. Rev. <u>106</u> , 993 (1957)].

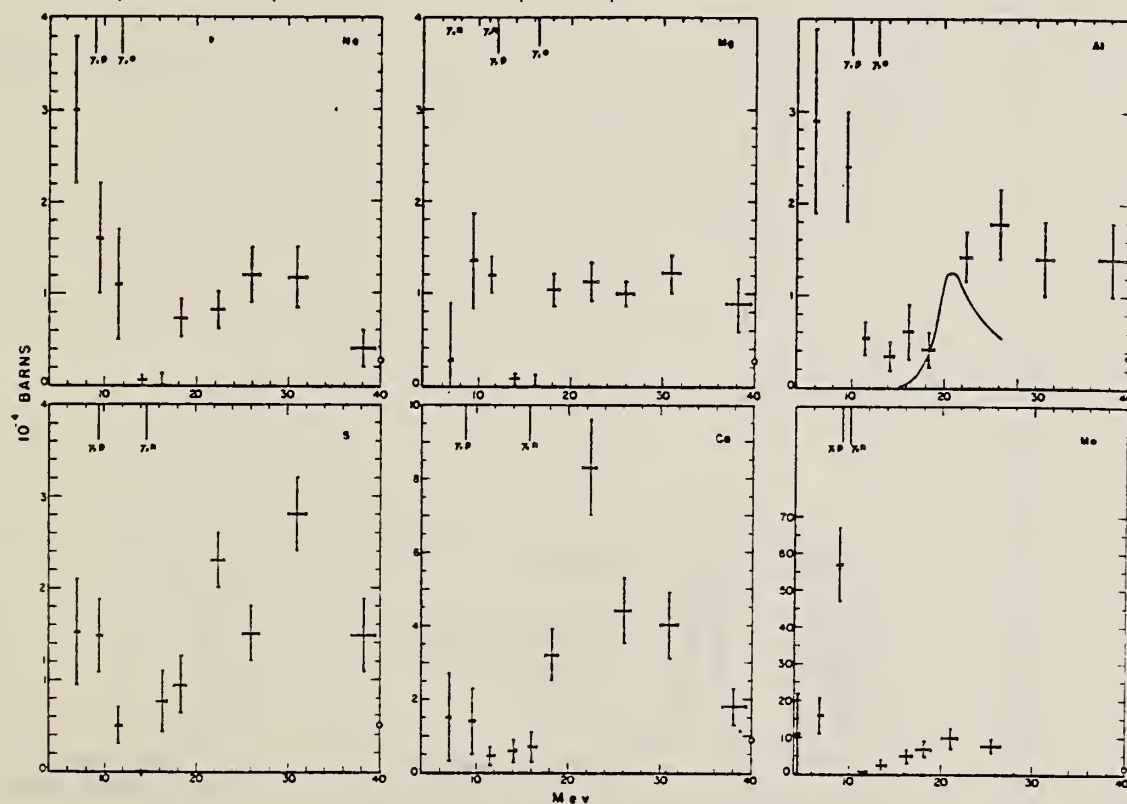


FIG. 4. The elastic scattering cross sections for Na, Mg, Al, S, Ca, and Mn. The indicated spread in energy is the width of the differential discriminator channel, and the standard deviations are based only on the number of counts. The vertical lines at the top represent the particle thresholds for the most important isotopes. The open circles at the extreme right indicate the magnitude of the Thomson cross section for Z free protons scattering coherently. The solid curve superimposed on the Al data is the scattering cross section calculated from the dispersion relation by substituting for $\sigma_n(E)$ in Eq. (6) the sum of the neutron and proton yield^{4,15} cross sections.

Elem. Sym.	A	Z
Mn	55	25
Ref. No. 57 Hi 1		EGF

Method Michigan University synchrotron; Victoreen counter; Betatron 21 min.

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(e,e' γ n)	63.5 81.5	42				No corrections made for finite signs ^{size} of nucleus. $Mn^{55}(\gamma,3n)Mn^{52*}$ cross section from Hines [Phys. Rev. <u>91</u> , 474(A), (1953)].

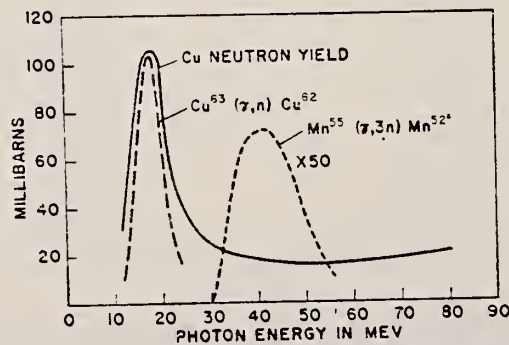
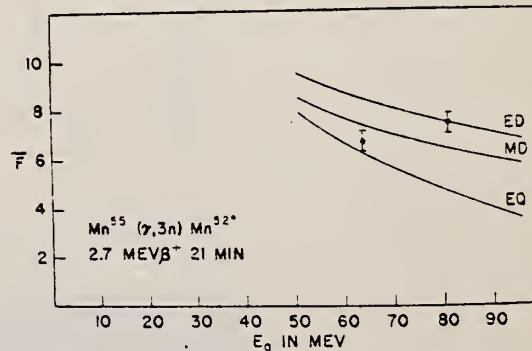


FIG. 1. Photoneutron yield cross section for Cu shown in comparison with Cu⁶³(γ,n)Cu⁶² and Mn⁵⁵($\gamma,3n$)Mn^{52*} cross sections



5. Experimental and theoretical values of \bar{F} for manganese.

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		NVB
58 Ch 2		

ACO Betatron

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	RLY	THR	C	THR	BF3-I		4PI

TABLE I
 MEASURED PHOTONEUTRON THRESHOLDS

THRESHOLD

Reaction	Measured Q value, Mev.	Other Q values, Mev.	Method	Reference
Mn ⁵⁵ (γ , n)Mn ⁵⁴	10.14 \pm 0.05	10.15 \pm 0.20	Threshold	Hanson <i>et al.</i> (1949)
		10.00 \pm 0.20	Threshold	Sher <i>et al.</i> (1951)
		10.14 \pm 0.26	Mass data	Wapstra (1955)
		10.28 \pm 0.07	Mass data	Duckworth (unpublished)
		10.09 \pm 0.10	Q ⁺ value	Jung and Pool (1956)
			Q ⁻ value	Duckworth (unpublished)
			Way <i>et al.</i> (1955)	

See 58 Ka 1 for cross sections

METHOD Betatron; neutron cross section; BF₃ counters; ion chamber monitor

REF. NO.

58 Ka 1

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XN	ABX	11-22	C	11-22	BF ₃ -I		4PI

Таблица 2

Пороги испускания фотонейтронов

Изотоп	B_n , Мэв	B_{nn} , Мэв	Изотоп	B_n , Мэв	B_{nn} , Мэв
V ⁵¹	11,16	20,5	L ¹³⁹	8,81	16,1
Mn ⁵⁵	10,14	19,2	Pr ¹⁴¹	9,46	17,6
Co ⁵⁹	10,44	18,6	Tb ¹⁵⁹	8,16	14,8
As ⁷⁵	10,24	18,1	Ho ¹⁶⁵	8,10	14,6
Y ⁸⁹	11,82	20,7	Tm ¹⁶⁹	8,00	14,7
Nb ⁹³	8,86	17,1	Lu ¹⁷⁵	7,77	14,2
Rh ¹⁰³	9,46	16,8	Ta ¹⁸¹	7,66	13,8
J ¹²⁷	9,14	16,2	Au ¹⁹⁷	7,96	13,3
Cs ¹³³	9,11	16,5	Bi ²⁰⁹	7,43	14,5

THRESHOLDS

не приведены, поскольку они превышают 22 Мэв во всех случаях, кроме золота, для которого $B_{nn}=21$ Мэв. Свойства сечений $\sigma_C(\gamma)$ сведены в табл. 3.

Таблица 1

Изотоп	$E_{макс.}$ Мэв	$\sigma_n(E_\gamma)$, барн	Γ , Мэв	Σ_n , Мэв-барн	$\gamma(22)$, 10^4 нейтрон/100 р-моль
V ⁵¹	18,4	0,062	5,2	0,33	1,62
Mn ⁵⁵	20,2	0,060	7,0	0,39	2,01
Co ⁵⁹	18,3	0,068	6,3	0,44	2,30
As ⁷⁵	16,4	0,090	9,5	0,74	4,25
Y ⁸⁹	17,1	0,172	5,2	0,93	5,33
Nb ⁹³	18,0	0,156	7,5	1,17	6,80
Rh ¹⁰³	17,5	0,160	9,4	1,40	8,28
J ¹²⁷	15,2	0,273	6,8	1,76	11,9
Cs ¹³³	16,5	0,238	7,7	1,59	10,7
La ¹³⁹	15,5	0,325	3,8	1,55	11,2
Pr ¹⁴¹	15,0	0,320	4,9	1,93	13,1
Tb ¹⁵⁹	15,6	0,274	9,8	2,49	18,1
Ho ¹⁶⁵	13,5	0,305	8,9	2,52	18,7
Tm ¹⁶⁹	16,4	0,250	8,4	1,91	14,9
Lu ¹⁷⁵	16,0	0,225	8,4	1,90	23,0
Ta ¹⁸¹	14,5	0,380	8,5	3,15	22,0
Au ¹⁹⁷	13,8	0,475	4,7	3,04	22,6
Bi ²⁰⁹	13,2	0,455	5,9	2,89	23,2

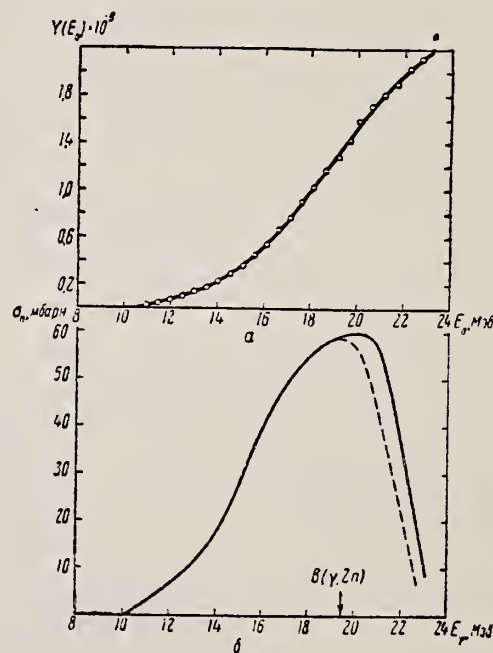


Рис. 2.

α — Выход фотонейтронов для Mn; δ — $\Sigma_n(E_\gamma)$ и $\sigma_C(\gamma)$ для Mn

Elem. Sym.	A	Z
Mn	55	25

Method 24 MeV betatron; neutron yield; BF_3 chamber, Lucite ionization chamber

Ref. No.	EH
59 Pa 2	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Mn}^{55}(\gamma, n)$	Bremss. 24	19.5 ± 0.25 16.75 ± 0.25	4.5 MeV 3.0 MeV			$\sigma_b = 62.7 \text{ mb.}$ $\sigma_a = 45.9 \text{ mb}$ $Q_0 = 0.73 \pm 0.14 \text{ b}$ compared to 1.26 from Coulomb excitation experiments of Mark <u>et al</u> [Phys. Rev. <u>98</u> , 1245 (1955)]. Data cannot be fitted with two resonances.

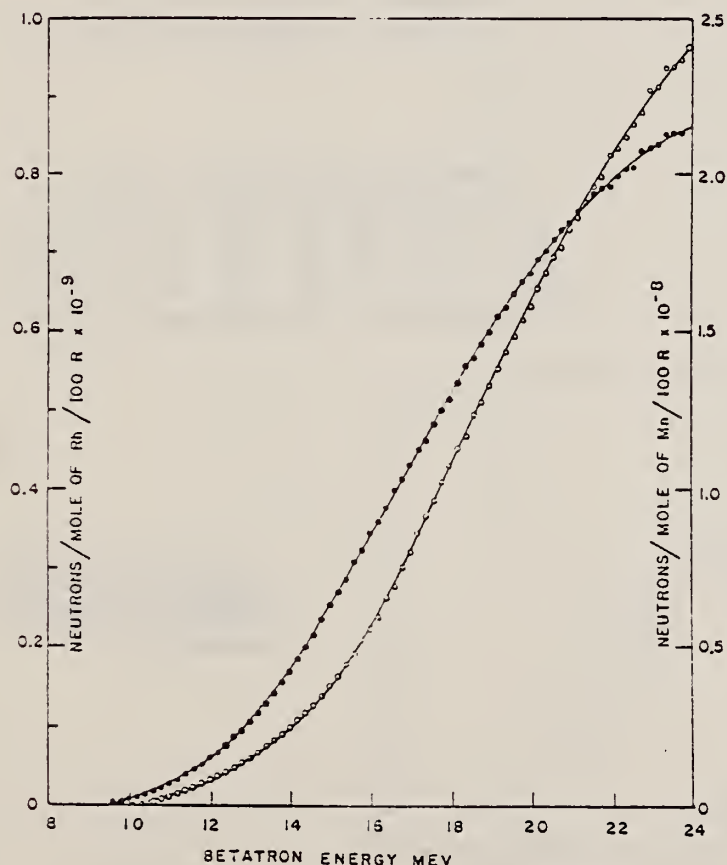


FIG. 1. Photoneutron yield versus betatron energy. \circ manganese; \bullet rhodium.

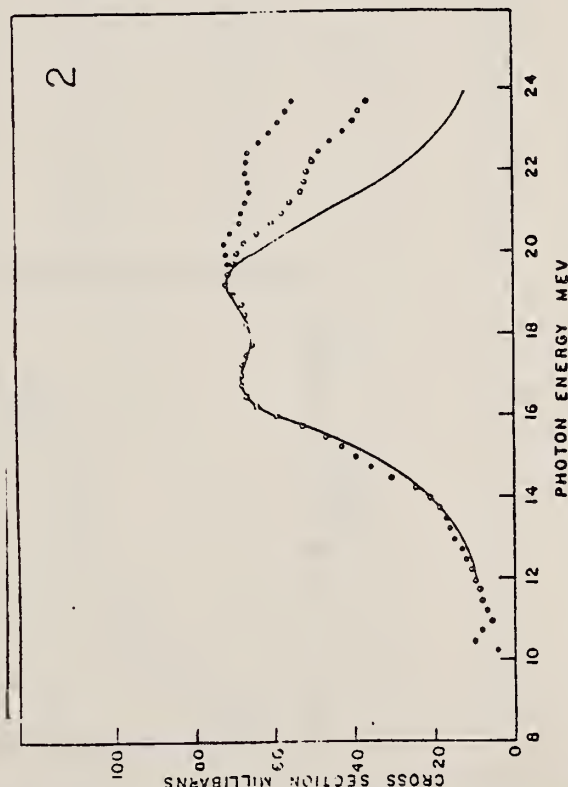


Fig. 2. $\sigma_1 + \sigma_2$ (\circ) and $\sigma_1 + 2\sigma_2$ (\bullet) for manganese versus photon energy. The full curve is compounded of two resonance curves whose parameters are given in the text.

Elem. Sym.	A	Z
Mn	55	25
Ref. No.		JHH
60 F1 1		

Method
Synchrotron; BF_3 counters in 4π geom.

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(γ, xn)	12-30	$16.8 \pm .25$	2.7	25 MeV 627 MeV-mb 12		$\sigma_{\text{max}} (16.8 \text{ MeV}) = 90 \text{ mb}$
		$19.75 \pm .25$	4.0 (From Breit-Wigner fit: see Table I)			$\sigma_{\text{max}} (19.75 \text{ MeV}) = 77 \text{ mb}$ Intrinsic quadrupole moment $Q_0 = +0.78 \pm 0.10 \text{ barn if}$ $\sigma_{\text{total}} \approx \sigma(\gamma, n) + \sigma(\gamma, 2n) \text{ in this}$ region, using $R_0 = 1.2 \times 10^{-13} \text{ cm.}$ In Figure 3, open circles are un- corrected for neutron multiplicity; closed circles are corrected. Integrated cross section is $\sigma(\gamma, n) + \sigma(\gamma, pn) + \sigma(\gamma, 2n) + \dots$

TABLE I. Parameters of Breit-Wigner fit to data.

Element	E_0 (MeV)	Γ_0 (MeV)	σ_0 (mb)	E_0 (MeV)	Γ_0 (MeV)	σ_0 (mb)	$\Gamma_{\text{total}}/\Gamma_{\text{res}}$
Manganese	16.8	2.7	70	19.75	4.0	64	1.35
Cobalt	16.5	2.0	78	19.0	4.0	78	2.00

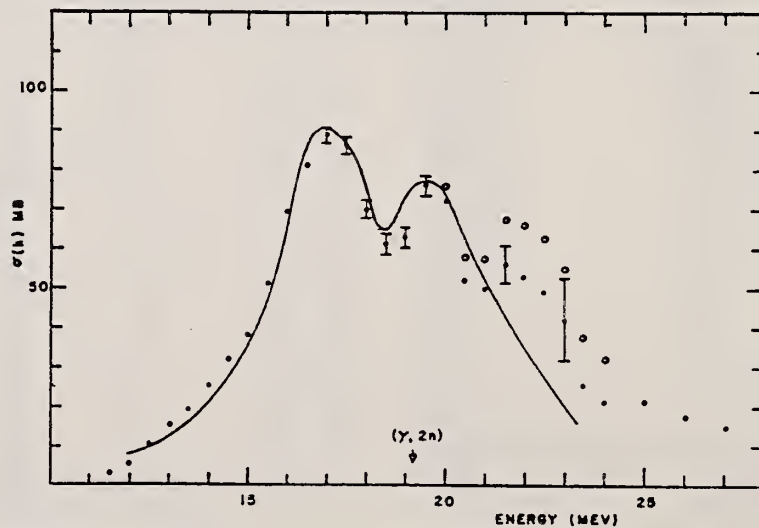


FIG. 3. Neutron cross section of manganese. Open circles represent uncorrected data. Closed circles represent data corrected for neutron multiplicity.

METHOD

Betatron; neutron threshold; ion chamber

REF. NO.

60 Ge 3

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NØX	THR	C	THR	BF3-I		4 PI

THRESHOLD

TABLE I. Summary and comparison of neutron separation energies inferred from present threshold measurements with values predicted from mass data and reaction energies. All energies are expressed in the center-of-mass system in Mev.

Reaction	No. runs	Present results	Other results	Method	Reference
$Mn^{55}(\gamma,n)Mn^{54}$	13	10.192 ± 0.020	10.209 ± 0.007 10.14 ± 0.05	mass data threshold	$\frac{g}{f}$

[†] See reference 4.
^{*} C. F. Giese and J. L. Benson, Phys. Rev. 110, 712 (1958).

Elem. Sym.	A	Z
Mn	55	25
Ref. No. 60 Re 1		JHM

γ 's from $F^{19}(\gamma, \alpha\gamma)$ reaction; protons from Van de Graaff; NaI

Ref. No.	
----------	--

60 Re 1

545

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$Mn^{55}(\gamma, \gamma)$	~ 7					$\langle \bar{\sigma} \rangle (E_p = 2.05 \text{ MeV}) = 0.31 \pm 0.05 \text{ mb}$

ELEM. SYM.	A	Z
Mn	55	25

METHOD

Betatron; fast neutron yield; angular distribution; Si threshold detector; ion chamber.

REF. NO.

61 Ba 2

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABY	THR- 22	C	22	THR-I		DST

In Table IV: $\bar{\sigma}$ = average cross section of detector weighted with neutron spectrum; ϕ = neutrons/100 roentgen/mole

$$W(\theta) = a_0 \sum_{n=1}^{\infty} (1 + a_n P_n(\cos\theta))$$

TABLE IV

I Element	II a_0	III a_1	IV a_2	V $(\bar{\sigma}\phi) \times 10^{22}$	VI $\phi_{\text{total}} (22 \text{ Mev}) \times 10^3$	VII $\phi_{\text{fast}}/\phi_{\text{total}}$
Vanadium	215 (1±0.06)	0.01±0.08	-0.00±0.10	6.05	0.21	0.12
Chromium	161 (1±0.03)	0.01±0.01	-0.05±0.05	4.05	0.17	0.10
Manganese	308 (1±0.02)	0.07±0.03	-0.09±0.04	7.61	0.25	0.12
Iron	200 (1±0.03)	0.05±0.04	-0.17±0.05	4.94	0.18	0.11
Cobalt	390 (1±0.02)	0.08±0.03	-0.22±0.01	9.63	0.26	0.15
Nickel	145 (1±0.05)	0.07±0.07	-0.23±0.09	3.58	0.12	0.12
Copper	347 (1±0.02)	0.05±0.03	-0.20±0.04	8.57	0.30	0.12
Arsenic	482 (1±0.03)	0.11±0.04	-0.21±0.05	11.91	0.33	0.15
Rubidium	638 (1±0.05)	0.13±0.06	-0.14±0.08	15.76		
Strontium	409 (1±0.05)	0.10±0.06	-0.17±0.08	10.10		
Yttrium	290 (1±0.10)	0.08±0.12	-0.12±0.15	7.16		
Silver	590 (1±0.04)	0.10±0.06	-0.22±0.08	14.57	0.87	0.07
Cadmium	905 (1±0.02)	0.02±0.02	-0.26±0.03	22.35		
Iodine	1133 (1±0.03)	0.04±0.04	-0.29±0.05	27.99	1.42	0.08
Barium	1018 (1±0.01)	0.10±0.06	-0.38±0.08	25.89		
Lanthanum	1595 (1±0.02)	0.02±0.03	-0.42±0.04	39.40	1.01	0.15
Cerium	1316 (1±0.05)	0.05±0.06	-0.39±0.08	32.50		
Dysprosium	1652 (1±0.08)	0.01±0.10	-0.31±0.13	40.80		
Tantalum	1558 (1±0.02)	0.04±0.03	-0.22±0.04	33.48	2.50	0.06
Tungsten	1365 (1±0.02)	-0.07±0.03	-0.24±0.04	33.71		
Mercury	1345 (1±0.02)	0.04±0.03	-0.31±0.04	33.22		
Lead	2274 (1±0.01)	0.02±0.02	-0.42±0.03	56.17	2.72	0.08
Bismuth	2162 (1±0.02)	0.05±0.03	-0.45±0.04	53.40	3.36	0.06
Thorium	3031 (1±0.01)	0.06±0.05	-0.32±0.07	74.87		
Uranium	4630 (1±0.02)	0.05±0.03	-0.17±0.04	114.36		

* $(\bar{\sigma}\phi) = 2.17 \times 10^7$ mb millibarn-neutron. Errors are standard errors due to counting statistics only.

Ref. No.	
61 Ta 1	JHH

Reaction	E or ΔE	E ₀	Γ	∫σdE	Jπ	Notes
(γ,n)	Bremss. 22					<p>$E_n > 6$ MeV.</p> <p>$W(\theta_n) = A + B \sin^2 \theta$ where $B/A = \approx 0$</p>

Figure 4: Angular distributions of fast photoneutrons as observed with the $\text{Si}^{28}(\text{n},\text{p})\text{Al}^{29}$ detector. Data normalized at 90° in each case.

REF. E. C. Booth, B. Chasan and K. A. Wright
Nucl. Phys. 57, 403-420 (1964)

ELEM. SYM.	A	Z
Mn	55	25

METHOD

Van de Graaff; resonance fluorescence

REF. NO.

64 Bo 1

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	1-3	C	1 - 3	NAI-D		100
		(0.5 - 3.0)		(0.5 - 3.0)			

ABI

TABLE I
Cases of observed resonance fluorescence

Nucleus multipol.	State (MeV)	Spin	Γ_0/Γ	$T(gw\Gamma_0^2/\Gamma^2)^{-1}$ (sec).	Mean lifetime T BCW (sec)	Mean lifetime T other (sec)	Ref.	Γ_0/Γ_w BCW
Mn ⁵⁵	0.00	$\frac{1}{2}^-$						
M1 ^a)	1.53	$\frac{3}{2}$	0.9	$27 \pm 8 \times 10^{-14}$	$15 \pm 4 \times 10^{-14}$			5×10^{-2}
[M1] ^a)	1.88	$[\frac{3}{2}^-]$	0.82	$23 \pm 7 \times 10^{-15}$	$15 \pm 5 \times 10^{-15} gW$			0.4
[M1] ^a)	2.20	$[\frac{3}{2}^-]$	?	$28^{+15}_{-11} \times 10^{-15}$				$0.16\Gamma/\Gamma_0$
[M1] ^a)	2.56	$[\frac{3}{2}^-]$	?	$17^{+15}_{-7} \times 10^{-15}$				$0.18\Gamma/\Gamma_0$

REF. NO.

64 Co 2

JOC

Carbon; $C^{12}(\gamma, n)$ monitor

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
C^{12}	ABY	THR - 20	C	20	BF ₃ -Y		4 PI

Table 1

Element	Yield (Ca) eV cm ² mol MeV	60 NZ/A (mb MeV)	$\frac{\Sigma}{0}$	$\frac{\Sigma}{0}$	$\frac{\Sigma}{0} / \frac{\Sigma}{0}$	Σ_m (MeV)	Σ_m (mb)
^{24}Cr	83×10^{-5}	777	1.21	2.1	0.53	18.5	97
^{25}Mn	108×10^{-5}	818	1.52	2.33	0.65	18.5	114
^{26}Fe	68×10^{-5}	832	0.83	1.46	0.60	17.5	75
^{27}Co	69×10^{-5}	373	1.08	1.32	0.59	17.5	92
^{28}Ni	44×10^{-5}	879	0.55	1.07	0.51	18.5	56
^{29}Cu	95×10^{-5}	947	1.06	1.99	0.53	17.5	98
^{30}Zn	38×10^{-5}	975	0.94	1.63	0.56	17.5	66
^{31}Ga	130×10^{-5}	1034	1.29	2.13	0.59	17.5	151
^{32}Ge	139×10^{-5}	1034	1.35	2.29	0.59	17.5	158
^{33}As	137×10^{-5}	1109	1.22	2.13	0.56	17.5	127

$$\frac{\Sigma}{0} = \frac{\int_0^{30} \sigma(\gamma, xn) dE}{60 \text{ NZ/A}}$$

Table 2

Element	maximum yield ($\times 10^{-5}$)	$\sigma_{-1}(Tn)$	$\sigma_{-1}(Tn) \times \left[\frac{2}{4\pi} \frac{Mc}{\hbar^2} \left(\frac{A}{NZ} \right)^{1/2} A^{-2/3} \right]$
^{6}C	4.0	3.54	2.13
^{8}O	5.2	4.95	1.92
^{11}Na	10.6	11.60	2.49
^{12}Mg	10.0	3.81	1.73
^{13}Al	15.9	13.92	2.30
^{14}Si	11.6	9.56	1.55
^{15}P	19.3	17.56	2.32
^{16}S	9.5	3.55	1.07
^{16}K	19.3	17.90	1.01
^{20}Ca	12.1	11.63	1.02
^{24}Cr	86	61.6	3.56
^{25}Mn	115	76.1	3.96
^{26}Fe	71	50.3	2.85
^{27}Co	64	60.5	2.04
^{28}Ni	40	34.2	1.59
^{29}Cu	102	72.3	1.06
^{30}Zn	93	65.7	2.03
^{31}Ga	140	93.6	3.31
^{32}Ge	150	101.5	3.36
^{33}As	151	99.5	3.12

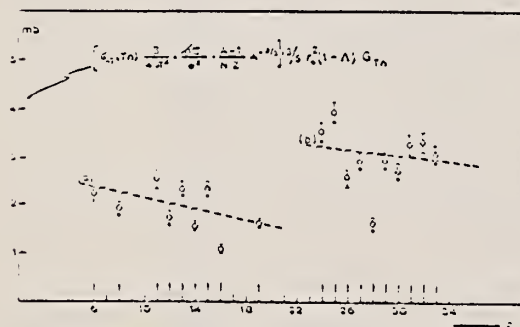


Fig. 2. Bromsstrahlung-weighted cross sections, $\sigma_{-1}(Tn)$, conveniently normalized, versus Z .

REF.			S. Costa, F. Ferrero, S. Ferroni and R. Malvano Proc. Paris Conference 1034 (1964)			ELEM. SYM.	A	Z
						Mn	55	25
METHOD						REF. NO.		
.100 MeV synchrotron						64 Co 3		JDM
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE	
			TYPE	RANGE	TYPE	RANGE		
G,N	AB I	THR-80	C	10-80	BF3-I		4PI	

TABLE

ELEMENT	Yield (36 MeV) $\left(\frac{n. cm^2}{mol. MeV} \times 10^8\right)$	Σ_0^{30}	Σ_0^{60}	$\Sigma_0^{80}/\Sigma_0^{30}$	σ_{-1} (mb)
²⁴ Cr	83	1.21	2.1	0.58	62
²⁵ Mn	108	1.52	2.33	0.65	76
²⁶ Fe	68	0.88	1.46	0.60	50
²⁷ Co	89	1.08	1.82	0.59	64
²⁸ Ni	44	0.55	1.07	0.51	34
²⁹ Cu	95	1.06	1.99	0.53	72
³⁰ Zn	88	0.94	1.68	0.56	66
³¹ Ga	130	1.29	2.18	0.59	94
³² Ge	139	1.35	2.29	0.59	101
³³ As	137	1.22	2.18	0.56	100

$\Sigma_0 = \frac{A}{60 NZ} \int_0^E \sigma(E) dE$ is the integrated cross section measured in units of
the classical dipole $60 NZ/A$ mb. MeV.

REF. W. B. Walters and J. P. Hummel
Phys. Rev. 150, 867 (1966)

ELEM. SYM. A Z

Mn 55 25

METHOD

Betatron

REF. NO.

66 Wa 1 JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,3N	RLY	THR-300	C	100-300	ACT-I		4PI
G,4P7N	RLY	THR-300	C	100-300	ACT-I		4PI

Measured isomeric yield ratios.

TABLE III. Summary of the results for the photoproduction of the Mn⁵⁵ isomers (spins 2 and 6).

Target isotope and spin	Bremsstrahlung energy (MeV)	Fraction of yield to high-spin isomer
Fe ^{54,56} (<i>I</i> =0)*	100	0.39±0.03
	150	0.36±0.02
	200	0.35±0.02
	250	0.37±0.02
Mn ⁵⁶ (<i>I</i> = $\frac{5}{2}$)	100	0.44±0.04
	150	0.48±0.02
	225	0.47±0.02
	300	0.47±0.02
Co ⁵⁹ (<i>I</i> = $\frac{7}{2}$)	150	0.62±0.02

* It is assumed that most of the yield is due to reactions involving the two lightest isotopes present in natural iron (Fe⁵⁴ and Fe⁵⁶).

TABLE II. Summary of the results for the photoproduction of the Sc⁴⁴ isomers (spins 2 and 6).

Target isotope and spin	Bremsstrahlung energy (MeV)	Fraction of yield to high-spin isomer
Sc ⁴⁴ (<i>I</i> = $\frac{7}{2}$)	50	0.21±0.04
	75	0.21±0.03
	175	0.20±0.02
	223	0.18±0.01
	264	0.17±0.02
	300	0.21±0.02
Fe ^{54,56} (<i>I</i> =0)*	250	0.38±0.02
Mn ⁵⁶ (<i>I</i> = $\frac{5}{2}$)	225	0.42±0.04
	300	0.39±0.02

* It is assumed that most of the yield is due to reactions involving the two lightest isotopes present in natural iron (Fe⁵⁴ and Fe⁵⁶).

REF. J. M. Loiseaux, J. M. Maison, and M. Langevin
J. de Physique 28, 11 (1967)

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		JOC
67 Lo 1		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G,G/	ABX	14-32	C	34	NAI-D		DST

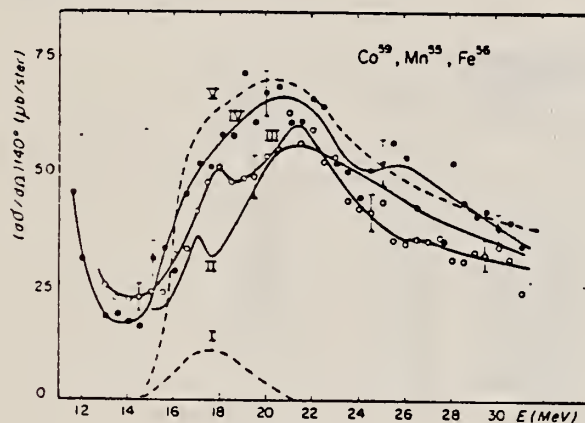


FIG. 10.

Sections efficaces différentielles de diffusion à 140° pour ⁵⁵Mn (courbe II), ⁵⁶Fe (courbe III), ⁵⁹Co (courbe IV).
Section efficace de diffusion tenseur (courbe I) et section efficace de diffusion scalaire - tenseur (courbe V) calculées avec les paramètres de Fultz et al. [16] pour ⁵⁹Co.

REF. W. J. Alston III, H. H. Wilson and E. C. Booth Nucl. Phys. <u>A116</u> , 281 (1968)			ELEM. SYM.	A	Z
			Mn	55	25
METHOD			REF. NO.		
			68 A1 1		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,G	LFT	0 - 3	C	4	130
		(2.75)			

Angle greater than 90° for all measurements.

SELF-ABSORPTION

TABLE 1
Direct and absorption measurements of resonance fluorescence

Nucleus	E_r (MeV)	J_r	Γ_0/Γ	$gW\Gamma_0\Gamma_0/\Gamma$ (meV)	Error (%)	This work Γ_0 (meV)	Other work Γ_0
⁵⁵ Mn	0.000	$\frac{1}{2}^-$					
	1.527	($\frac{1}{2}^-$)	0.9	5.2	25	8-12	
				abs a)	40	8.0	
	1.884	?	0.82 b)	41	25	50/gW	
				abs a)	10	55/g	
	2.197	?	(0.8) c)	17	25	21/gW	
				abs	20	17/g	
	2.252	?	(0.9) d)	17	25	19/gW	
				abs	20	13/g	
	2.365	?	?	3.5	36	(2-6) Γ/Γ_0	
⁵⁹ Co	2.564	?	(1.0)	50	25	50/gW	
				abs a)	20	61/g	
	2.751	?	?	6.7	42	6.7(Γ/Γ_0)/gW	
	0.000	$\frac{7}{2}^-$					
	1.187	($\frac{7}{2}^-$)	(1.0)	6.8	25	7.5	0.33(E2) ^{d)}
				abs	25 a)	12	
		($\frac{7}{2}^-$)	(1.0)	6.8	25	(5.4-6.5)	0.27(E2)
				abs	25 a)	9.6	
	0.000	$\frac{3}{2}^-$					
	1.414	$\frac{3}{2}^-$	?	1.6	30	(1.1-1.7) Γ/Γ_0	
⁶³ Cu	1.551	$\frac{3}{2}^-$	?	1.7	37	(1.7-2.5) Γ/Γ_0	0.1(E2) e)
	0.000	$\frac{3}{2}^-$					
	0.872	($\frac{3}{2}^-$)	0.95	1.1	35	0.8/W	
⁶⁹ Ga	1.107	($\frac{3}{2}^-$)	0.95	8.0	20	8.4/W	
	0.000	$\frac{1}{2}^-$					
	0.86	?	?	1.7	20	1.7 $\Gamma/gW\Gamma_0$	
⁷⁵ As	1.07	?	?	2.6	30	2.6 $\Gamma/gW\Gamma_0$	
	1.35	?	?	3.6	20	3.6 $\Gamma/gW\Gamma_0$	
	0.000	$\frac{1}{2}^-$					
⁸⁹ Y	1.51	$\frac{1}{2}^-$	(1.0)	52 a)	30	23	0.37(E2) ^{f)}
				abs a)	15	22	

a) Measured with NaI.

b) Ref. ¹⁴⁾.

c) Measured with a Ge(Li) detector to $\pm 10\%$.

d) Ref. ¹³⁾. e) Ref. ¹⁴⁾. f) Ref. ²²⁾.

¹³ D.G. Alkhazov, K.I. Erokhina and I.K. Lemberg, Izv. Akad. Nauk. SSSR (ser. fiz.) 28 (1964) 1667.

¹⁴ B.G. Harvey, J.R. Meriwether and A. Bussiere, Nucl. Phys. 70 (1965) 305.

²³ G.A. Peterson and J. Alster, Phys. Rev. 166 (1968) 136.

²⁴ N. Nath, M.A. Rothman, D.M. Van Patter and C.E. Mandeville, Nucl. Phys. 13 (1959) 74.

[over]

TABLE 2
Transition strengths for ^{55}Mn levels

Energy (MeV)	Transition	Multipolarity	$\Gamma_{\text{exp.}}(\text{M1})$ $\times 1/10$ (meV)	$\Gamma_0(\text{E2})$	$\Gamma_0(\text{M1})$ calc. ^{a)} (meV)	$\Gamma_0(\text{M1} + \text{E2})$ present work (meV)
0.983	$\frac{5}{2}^- \rightarrow \frac{3}{2}^-$	E2				< 1 ^{b)}
1.527	$\frac{5}{2}^- \rightarrow \frac{3}{2}^-$	(M1+E2)	7	0.5	1.9	8 ± 3
1.884	$\frac{7}{2}^- \rightarrow \frac{5}{2}^-$	(M1+E2)	15		43	41 ± 6
2.197	$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	(M1+E2)	22		111	25 ± 5
2.252	$\frac{5}{2}^- \rightarrow \frac{3}{2}^-$	(M1+E2)	24			13 ± 3 ^{c)}
2.564	$\frac{3}{2}^- \rightarrow \frac{1}{2}^-$	(M1+E2)	36		2.7	91 ± 18
	$\frac{5}{2}^- \rightarrow \frac{3}{2}^-$	(M1+E2)	36		1.0	61 ± 12
	$\frac{7}{2}^- \rightarrow \frac{5}{2}^-$	(M1+E2)	36		16	45 ± 9

^{a)} Ref. ¹⁰⁾.

^{b)} Assuming $\Gamma_0/\Gamma = 0.07$ from ref. ¹¹⁾.

^{c)} Strength from the $2.365 \rightarrow 0.127$ transition may be contributing to this partial width.

¹⁰⁾ J. Vervier, Nucl. Phys. 78 (1966) 497.

²⁴⁾ N. Nath, M.A. Rothman, D.M. Van Patter and C.E. Mandeville,
Nucl. Phys. 13 (1959) 74.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
$\$G, XN$	SPC	THR-85	C	85	CCH	1-15	135

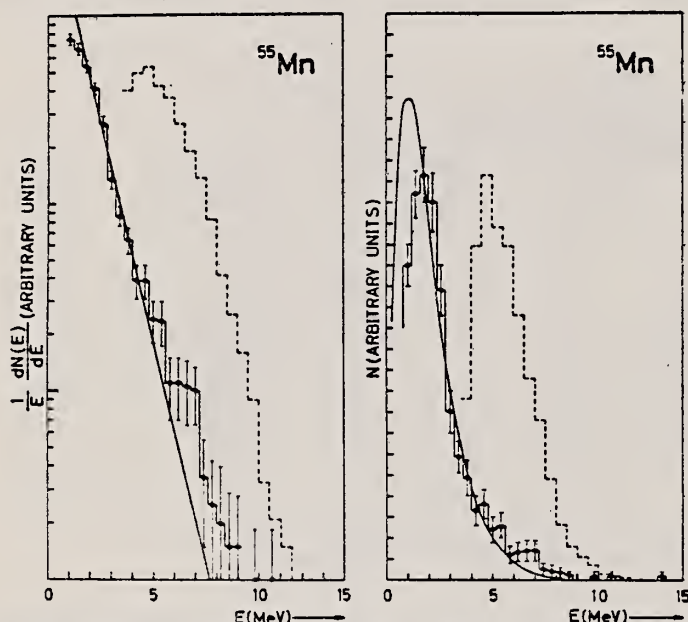


Fig. 4. Energy spectrum of photoneutrons from ^{55}Mn compared with the spectrum of photoprotons ($E_{\gamma \text{ max}} = 20.5 \text{ MeV}$) deduced from ref. ²⁷) (dashed histogram). The spectra are normalized to maximum value of N . The full line has the same meaning as in fig. 2.

²⁷K. Shoda, Nucl. Phys. 72, 305 (1965).

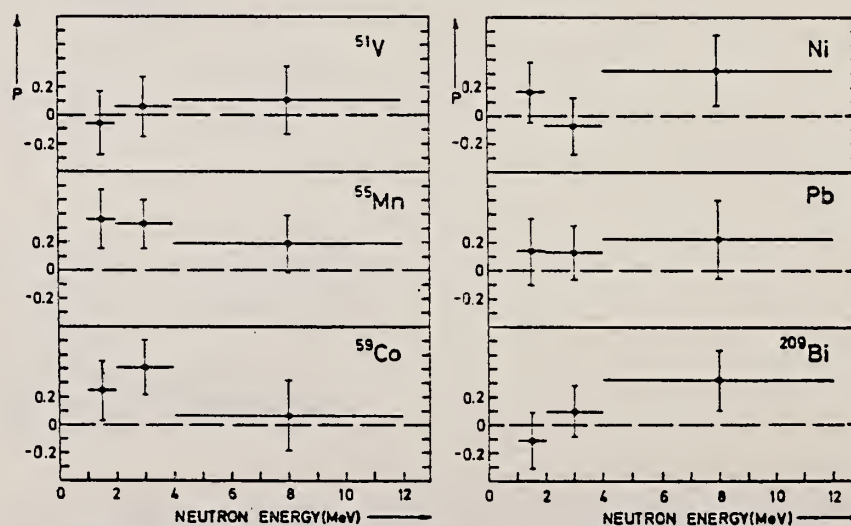


Fig. 7. Polarization of photoneutrons from ^{51}V , ^{55}Mn , ^{59}Co , natural Ni, natural Pb and ^{209}Bi .
PHOTONEUTRON POLARIZATION

REF. J. W. Jury, J. S. Hewitt, and K. G. McNeill Can. J. Phys. <u>46</u> , 1823 (1968)			ELEM. SYM. Mn	A . 55	Z 25
METHOD			REF. NO. 68 Ju 1		EGF
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,N	NOX	THR - 22	C	22	DST

$$W(\theta) = a_0 + a_1P_1 + a_2P_2$$

TABLE I

Target element	Z	Energy	a_0^*	a_1/a_0	a_2/a_0
Vanadium	23	32	640±50	0.11±0.10	-0.09±0.11
Chromium	24	22	365±39	0.02±0.08	0.00±0.10
Manganese	25	22	450±33	0.07±0.05	-0.11±0.06
Bromine	35	27	874±54	0.05±0.06	-0.15±0.08
Molybdenum	42	22	610±60	0.09±0.05	-0.35±0.06
Ruthenium	44	27	1100±25	0.12±0.02	-0.29±0.03
Rhodium	45	27	1270±47	0.06±0.03	-0.14±0.03
Palladium	46	27	1350±29	0.26±0.02	-0.12±0.02
Antimony	51	27	2140±62	0.04±0.08	-0.25±0.11
Lanthanum	57	27	1940±70	0.12±0.10	-0.52±0.14
Praseodymium	59	30	1800±58	0.20±0.08	-0.40±0.09
Platinum	78	27	2600±52	0.17±0.02	-0.15±0.03
Lead	82	22	2274±59	0.08±0.08	-0.46±0.09

*The yield per mole per 100 r was normalized to a yield of 2274 for the lead sample at the same energy.

REF. K. Shoda, K. Abe, T. Ishizuka, N. Kawamura, M. Oyamada,
and Baik-Nung Sung
J. Phys. Soc. Japan 25, 664 (1968)

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		
68 Sh 3		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XP	ABX	THR-23	C	13-23	SCI- I		DST

SPECTRA ALSO GIVEN

Table II. Anisotropic factor B/A of angular distributions determined by least-squares fits with $A+B\sin^2\theta$.

^{55}Mn	
$E_{\gamma\text{ max}}=20.5\text{ MeV}$	
$E_p(\text{MeV})$	B/A
2.8-5.2	0.1 ± 0.2
5.2-6.1	1.3 ± 0.3
$6.1\leq$	2.4 ± 0.6
$2.8\leq$	0.6 ± 0.1

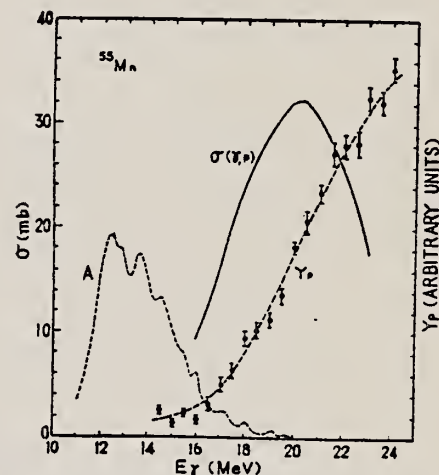


Fig. 14. Comparison among the photoproton cross sections on ^{55}Mn . Curve A is the cross section calculated from the present energy distribution under the assumption that the residual nucleus is completely left in the ground state. Photoproton yield curve using ZnS(Ag) scintillation counters and the cross section calculated from it are indicated by Y_p and $\sigma(\gamma, p)$ respectively.

REF. H. G. De Carvalho, V. Di Napoli, D. Margadonna, F. Salvetti and K. Tesch Nucl. Phys. <u>A126</u> , 505 (1969)			ELEM. SYM. Mn	A 55	Z 25
METHOD			REF. NO. 69 De 1		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,N	ABY	THR-999	C	2-6	4PI
G,3N	ABY	THR-999	C	2-6	4PI
				(2.0-5.5)	

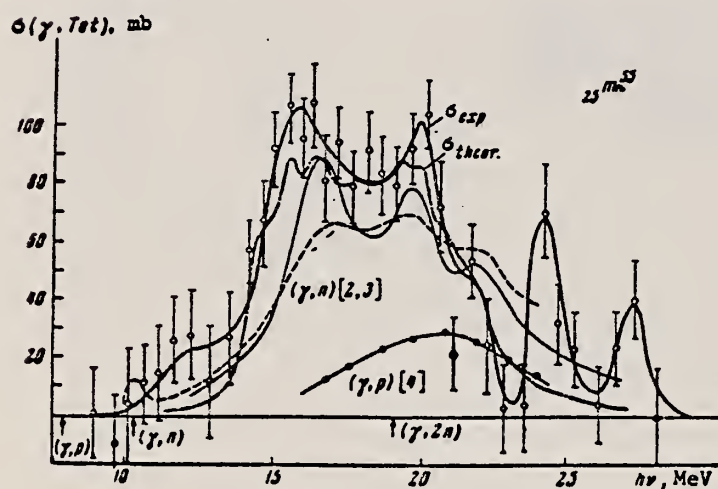
Yield per equivalent quantum.

999 = 5.5 GEV

In addition to the reactions mentioned above, we measured in the energy range 2-5.5 GeV, the following reactions: $^{55}\text{Mn}(\gamma, n)$, $^{55}\text{Mn}(\gamma, 3n)$, $^{103}\text{Rh}(\gamma, 2n)$ and $^{127}\text{I}(\gamma, 3n)$. The resulting cross sections per equivalent quantum are 43 mb, 0.55 mb, 21 mb and 9.5 mb, respectively. Within the experimental error of 20 %, we found no variation of these cross sections with the maximum bremsstrahlung energy.

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		hmg
69 Do 1		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G, MU-T	ABX	10-30	C	10-260	MAG-D	10-28	4PI



Cross section for the photo-absorption by Mn^{55} nuclei in the giant-resonance region.

REF.

R. Garfagnini, G. Piragino & A. Zanini
 Atti Accad. Naz. Lincei, Rend.
 Cl. Sci. Fis. Mat. Natur. 47, 33 (1969)

ELEM. SYM.

A

Z

Mn

55

25

METHOD

REF. NO.

69 Ga 3

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	SPC	11-85	C	85	CCH-D		135

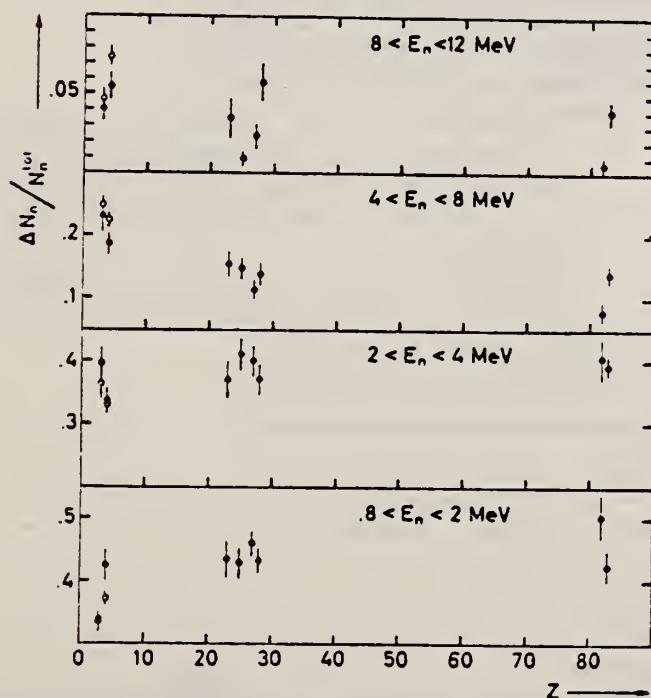


Fig. 1. - Percentage of the photoneutrons emitted at 135° , in the respective energy interval as a function of Z , by a γ -ray bremsstrahlung beam with $E_{\gamma \text{ max}} = 85$ MeV. The open circles represent the values obtained at 60° for ${}^7\text{Li}$ and ${}^9\text{Be}$.

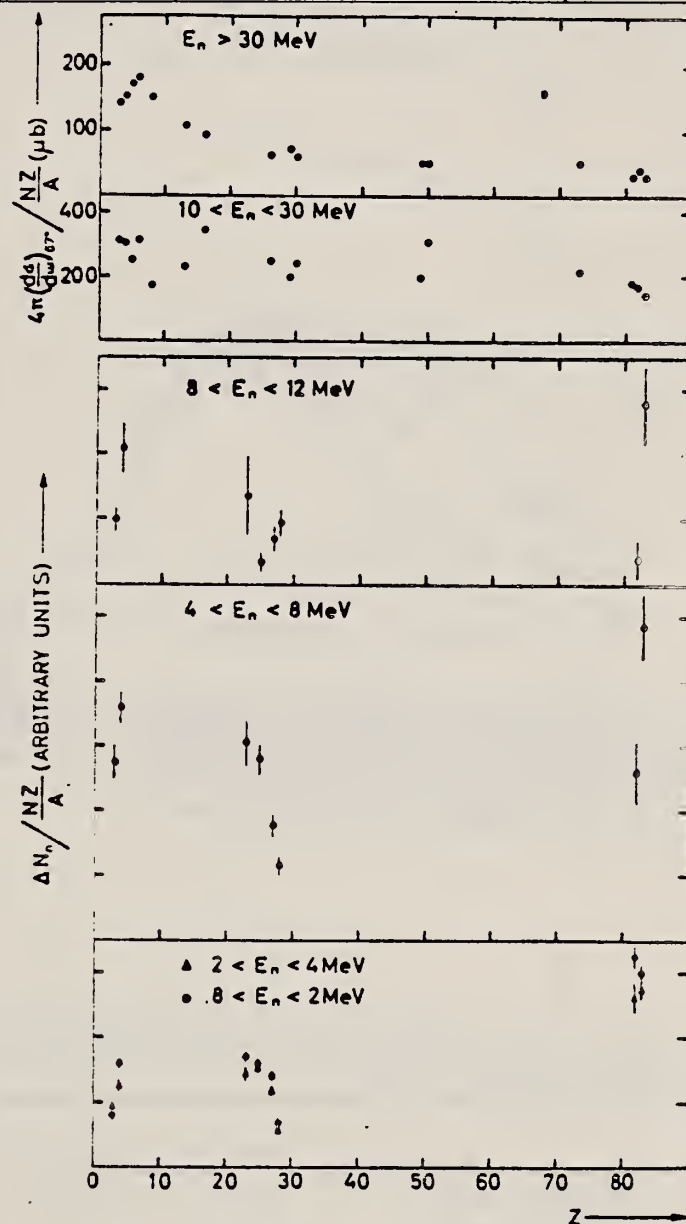


Fig. 2. - Number of photoneutrons emitted at 135° , normalized to the sum rule factor NZ/A , as a function of Z . In the upper part is reported the effective cross section divided by NZ/A for photoproduction of fast neutrons by 55-85 MeV bremsstrahlung photons as deduced by Kaushal *et al.* [1].

327 N.N. Kaushal *et al.*, Phys. Rev. 175, 1330 (1968).

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.	69 Th 1	
	hmg	

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE	DETECTOR	ANGLE
			TYPE	TYPE	
			RANGE	RANGE	
$E, E/$	ABX	0-4	D	MAG-D	DST
		(.98 - 3.05)	(50.2-60.2)		

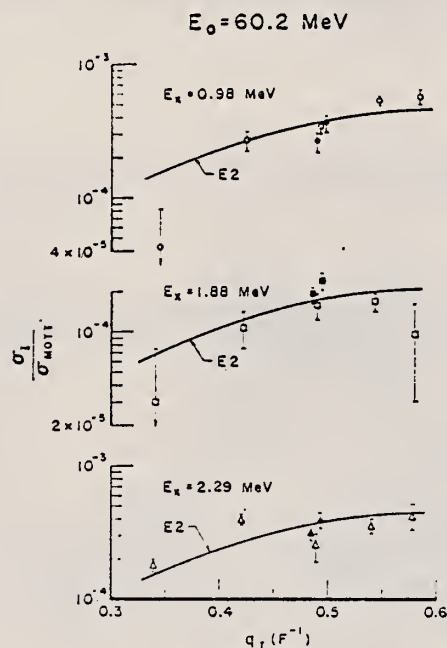


FIG. 3. Differential inelastic cross section σ_I in units of the Mott cross section σ_{Mott} as a function of the inelastic momentum transfer q_I for the 0.98-, 1.88-, and 2.29-MeV transitions in Mn^{55} . Open symbols represent points taken at $E_0 = 60.2$ MeV. Closed symbols refer to additional points taken at $q_I = 0.49$ F^{-1} , but different electron energies (see text). The best theoretical fits assuming pure $E2$ transitions are given by the solid lines.

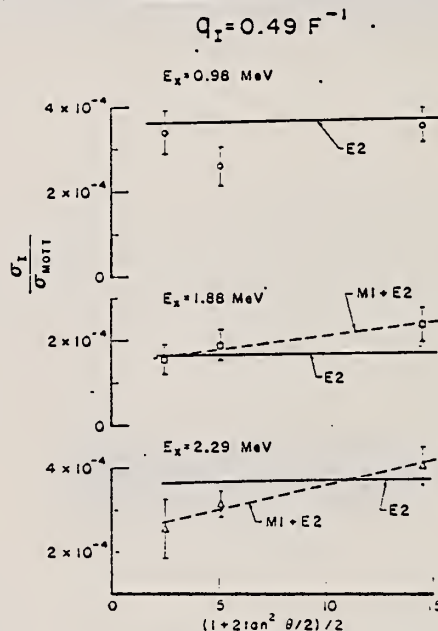


FIG. 4. Differential inelastic cross section σ_I divided by the Mott cross section σ_{Mott} , taken at constant inelastic momentum transfer, as a function of $\frac{1}{2}(1 + 2 \tan^2 \theta/2)$, i.e., points at $q_I = 0.49$ F^{-1} of Fig. 3 replotted. The solid lines represent the best theoretical fits from Fig. 3 for pure $E2$ transitions. The dashed lines are obtained under the assumption of an $E2$ - $M1$ mixture (see text).

- ¹I. Gabrielli, B. G. Harvey, D. L. Hendrie, J. Mahoney, J. R. Meriwether, and T. Valentine, Nuovo Cimento (to be published).
- ²R. J. Peterson, Ann. Phys. (N.Y.) 53, 40 (1969).
- ⁴W. J. Alston, III, H. H. Wilson, and E. C. Booth, Nucl. Phys. A116, 281 (1968).

TABLE III. Results for inelastic scattering. E_x is the excitation energy, J^π is the spin and parity of corresponding level, $B(E2^\uparrow)$ is the reduced transition probability, and Γ_0^γ is the ground-state radiation width. The $B(E2)$'s quoted as the results of this work have been obtained assuming the strict hydrodynamical model. The model dependence was taken into account by adding a $\pm 15\%$ uncertainty to the statistical error (see text).

	0.98 ($\frac{1}{2}^-$)	1.53 ($\frac{3}{2}^-$)	E_x (MeV), J^π 1.88 ($\frac{3}{2}^-$)	(2.29)	(3.05)
$B(E2^\uparrow)(F^4)$, this work	147 ± 30	(28 ± 16)	68 ± 15	154 ± 30	(34 ± 10)
$B(E2^\uparrow)(F^4)$, (α, α') ^a	167.0	...	119.0	89.4 ^d	
$B(E2^\uparrow)(F^4)$, (p, p') ^b	201	...	125	125 ^d	
$\Gamma_0^\gamma(E2)(10^{-3} \text{ eV})$, this work	0.066 ± 0.014	(0.28 ± 0.16)	0.96 ± 0.21	...	...
$\Gamma_0^\gamma(M1 + E2)(10^{-3} \text{ eV})$, (RF) ^c	...	8 ± 3	41 ± 6	...	...
$\delta^2 = \Gamma_0^\gamma(E2)/\Gamma_0^\gamma(M1)$	...	(0.04 ± 0.04)	0.024 ± 0.009	...	...

^a Reference 1.
^b Reference 2.

^c Reference 4.
^d Strengths of the 2.25- and 2.37-MeV transitions were added.

REF.

B. S. Ishkhanov, I. M. Kapitonov, E. V. Lazutin, I. M. Piskarev,
and O. P. Shevchenko
Izv. Akad. Nauk Fiz. 34, 2228 (1970)
Bull. Acad. Sci. USSR Phys. 34, 1988 (1970)

ELEM. SYM.	A	Z
Mn	55	25

METHOD	REF. NO.	
	70 Is 7	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	10- 30	C	7- 30	BF3-I		4PI

$$\int_{10}^{29.5} \sigma(\gamma, xn) dE = 780 \pm 80 \text{ MeV mb}$$

$$\int_0^{29.5} \sigma(\gamma, SN) dE = 620 \pm 60 \text{ MeV mb}$$

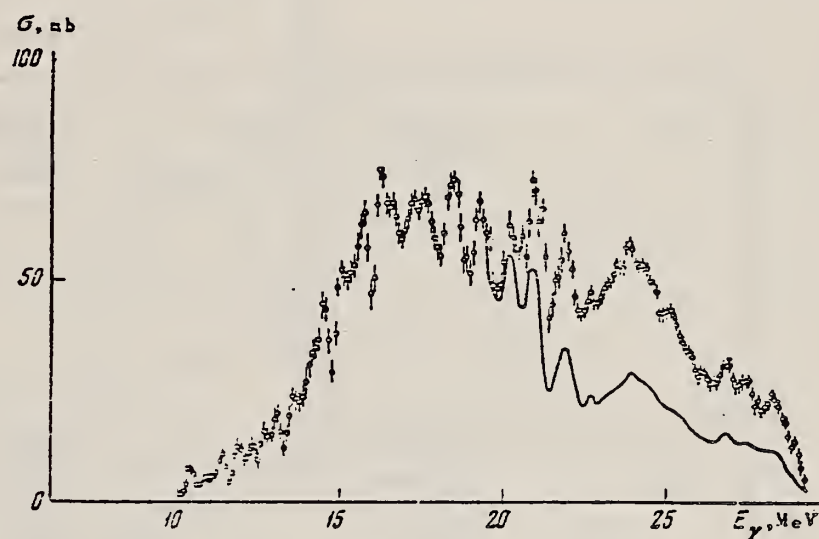


Fig.1. Photonuclear cross section $\sigma(\gamma, Tn) = \sigma(\gamma, n) + \sigma(\gamma, np) + 2\sigma(\gamma, 2n)$ for ^{55}Mn . The full curve shows the cross section $\sigma(\gamma, n) + \sigma(\gamma, np) + \sigma(\gamma, 2n)$ above the $(\gamma, 2n)$ threshold.

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		egf
71 Ku 2		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SPL	ABY	THR-999	C	999	ACT- I		4PI

$\sigma_q(A, Z) = K \exp [PA - R(A - SZ + TZ^2)^2]$, cross section per equivalent quantum.

999 = 1.5 GeV

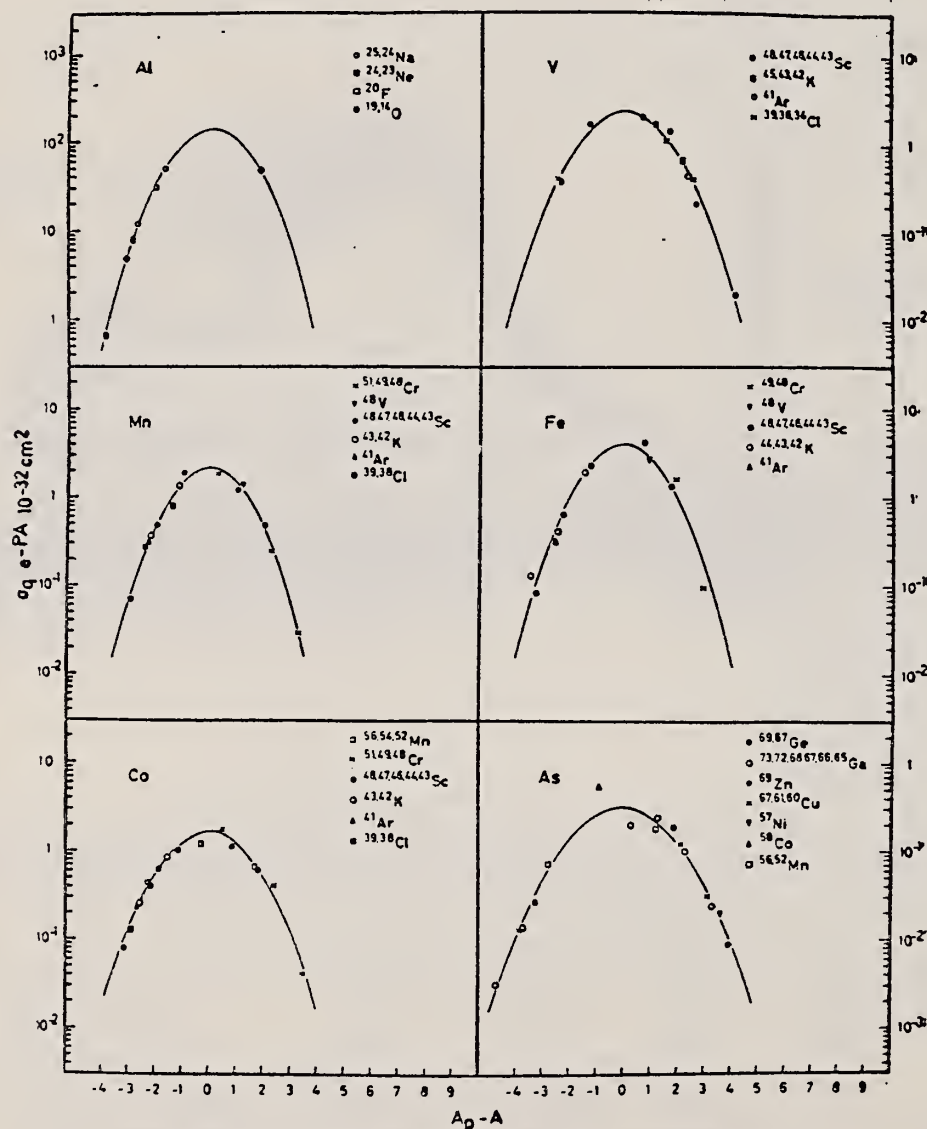


Fig. 4. Yield distributions from various targets with bremsstrahlung of 1.5 GeV.

[over]

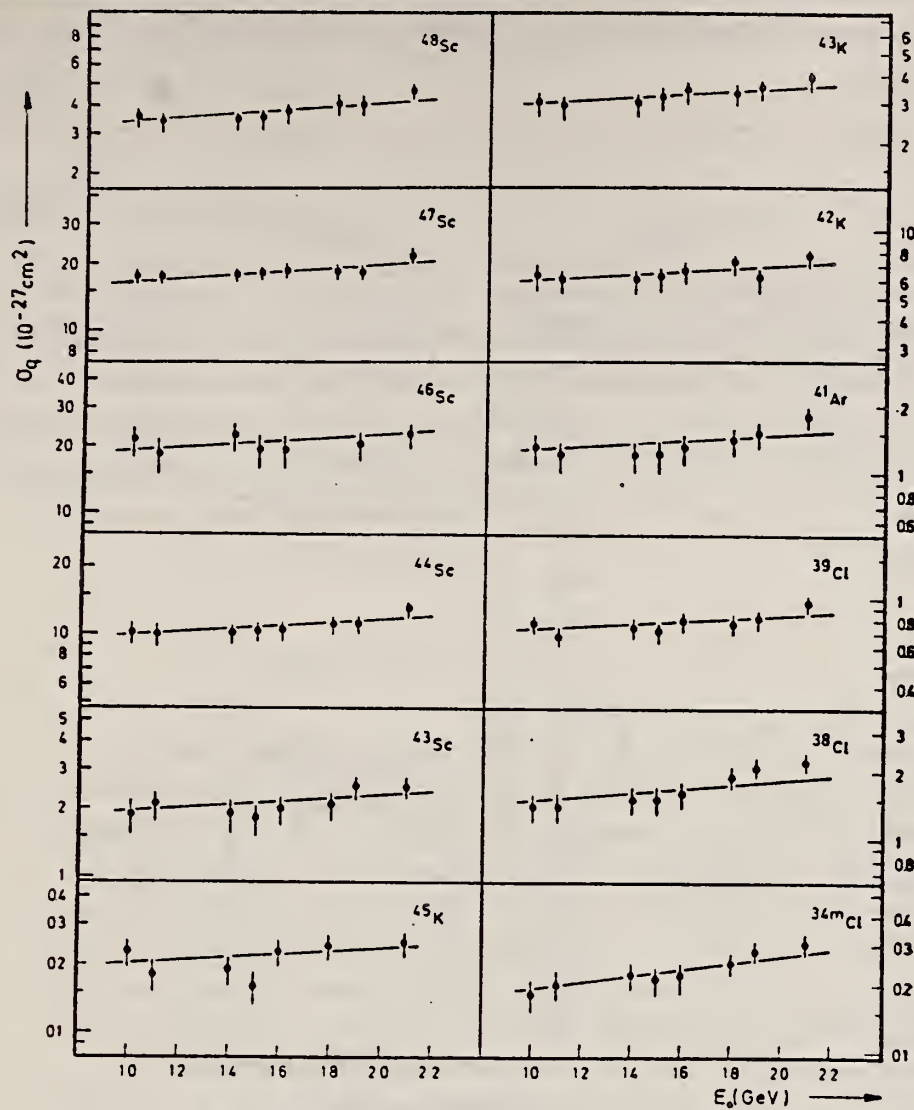


Fig. 5. Yields of spallation products using vanadium targets.

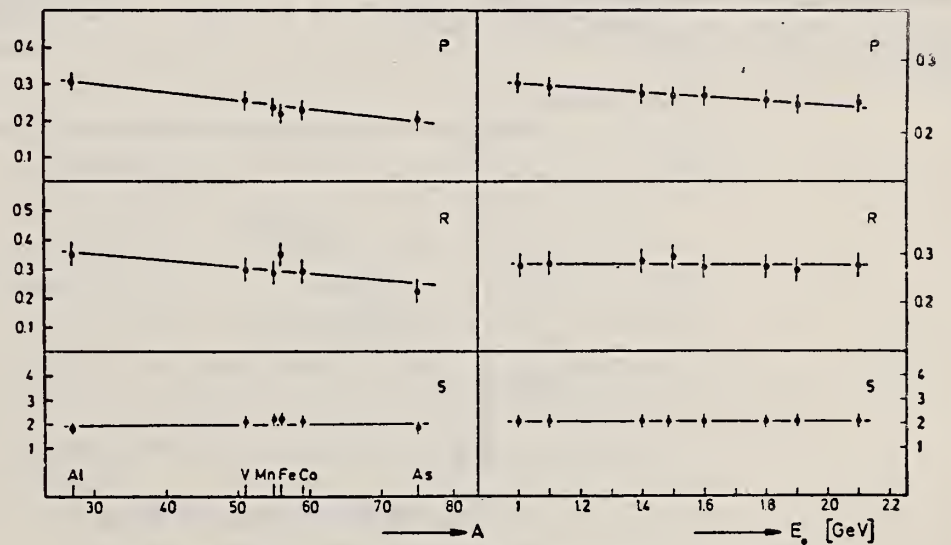


Fig. 6. Behaviour of the parameters P , R and S as functions of A and E_0 .

Tatsuya Saito
Nippon Kagaku Zasshi 92, 164 (1971)

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		
71 Sa 1		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	10-68	C	10-68	ACT-I		4PI

Nippon Kagaku Zasshi. 92, 164~168(1971)

The Yields of Radioactivities Induced by (γ, n) Reactions with Bremsstrahlung up to 68 MeV

by Tatsuya SAITO

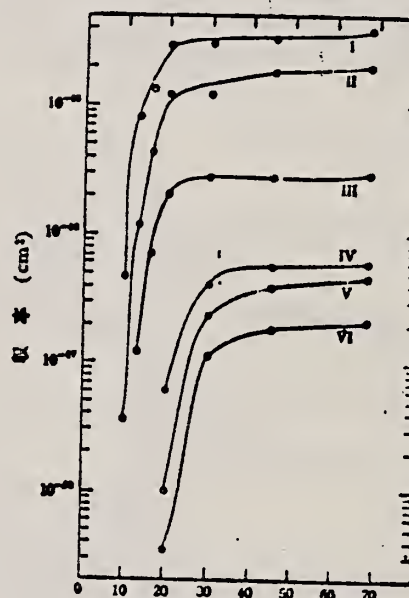
The (γ, n) yields of 12 target nuclides have been measured at 10, 13, 16, 30, 45 and 68 MeV bremsstrahlung by observing the induced activities.

The energy dependence of the yields has been investigated extensively in the same way as in the previous work at 20 MeV bremsstrahlung.

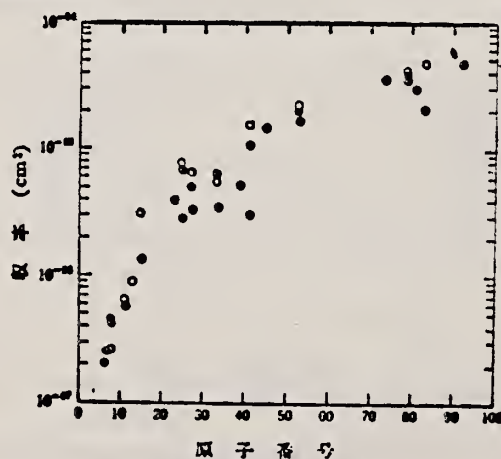
In the case of heavy nuclides, the yields rise greatly as a function of maximum bombarding energy up to 20 MeV, and rise gradually from 20 MeV up to 68 MeV. However, in the case of light nuclides, the yields rise greatly up to 30 MeV, because the neutron separation energies of light ones are larger than those of heavy ones, and the bremsstrahlung spectrum covers the giant resonance and so the yields rise gradually from 30 MeV up to 68 MeV.

The yields have approximately been estimated from the parameter of the giant resonance, that is the peak cross section and the half width, in order to compare with the experimental data. As a result, the experimental data of light nuclides and heavy ones are nearly in agreement with the estimated data of Nathans et al., Jolins et al. and Montalbetti et al., but those of medium weight ones are relatively lower values.

Department of Chemistry, Faculty of Science, Tohoku University; Katahira-cho, Sendai-shi, Japan

図3 (γ, n) 反応の収率

I: $^{197}\text{Au}(\gamma, n)^{196}\text{Au}$, II: $^{199}\text{Au}(\gamma, n)^{198}\text{Au}$
 III: $^{199}\text{Au}(\gamma, n)^{198}\text{Au}$, IV: $^{199}\text{Au}(\gamma, n)^{198}\text{Au}$
 V: $^{199}\text{Au}(\gamma, n)^{198}\text{Au}$, VI: $^{199}\text{Au}(\gamma, n)^{198}\text{Au}$

図3 (γ, n) 反応の収率

●: 実験値, ○: John's 値,
 ○: Nathans 値, ○: Montalbetti 値

図4 (γ, n) 反応の収率の比較

ELEM. SYM.	A	Z
Mn	55	25

METHOD	REF. NO.	
	73 A1 6	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	10- 37	D	10- 37	BF3-I		4PI
G,2N	ABX	17- 37	D	17- 37	BF3-I		4PI
G,3N	ABX	29- 37	D	29- 37	BF3-I		4PI

518+

We have measured the photoneutron cross sections for ^{55}Mn with nearly monoenergetic photons from in-flight annihilation of positrons from the new Livermore electron-positron linac. The technique and apparatus used were nearly identical to those used in the experiments on the nickel isotopes.¹ Measurements at each energy were also made of the ^{59}Co cross sections without changing the accelerator or beam-transport system tuning. This provides added confidence that fine structure observed in one isotope but not the other is indeed an effect of the nuclear dynamics and not a fluctuation caused by the apparatus. The ^{59}Co results are reported in a separate paper.²

Our results are shown in Fig. 1. The photon energy resolution is approximately 100 keV. The error bars shown are statistical only. Systematic errors are approximately the same as for the nickel isotopes.¹

The giant resonance in ^{55}Mn is unusually broad, and is divided into three main groups of sub-structures, the first two of which have nearly equal peak cross sections of about 65-70 mb and central energies of about 17 and 19.5 MeV. The third large cluster of strength lies near 23 MeV with a peak cross section a bit greater than 50 mb; this cluster is located near the maximum in the $(\gamma,2n)$ cross section. The $(\gamma,2n)$ cross section has a peak value of just over 20 mb and an integrated cross section (to 36.5 MeV) of 166 MeV-mb. This is to be compared with a total photoneutron integrated cross section of 805 MeV-mb. The statistical accuracy of the $(\gamma,3n)$ cross section measurement is very poor, but one can conclude that the cross section is quite small up to 37 MeV.

Superimposed on the gross structure in the giant-resonance region, a rather rich fine structure can be observed. We note particularly the structure on the low-energy edge of the giant resonance, including the sharp peak right at the (γ,n) threshold, a behavior similar to that observed in ^{58}Ni .¹

(over)

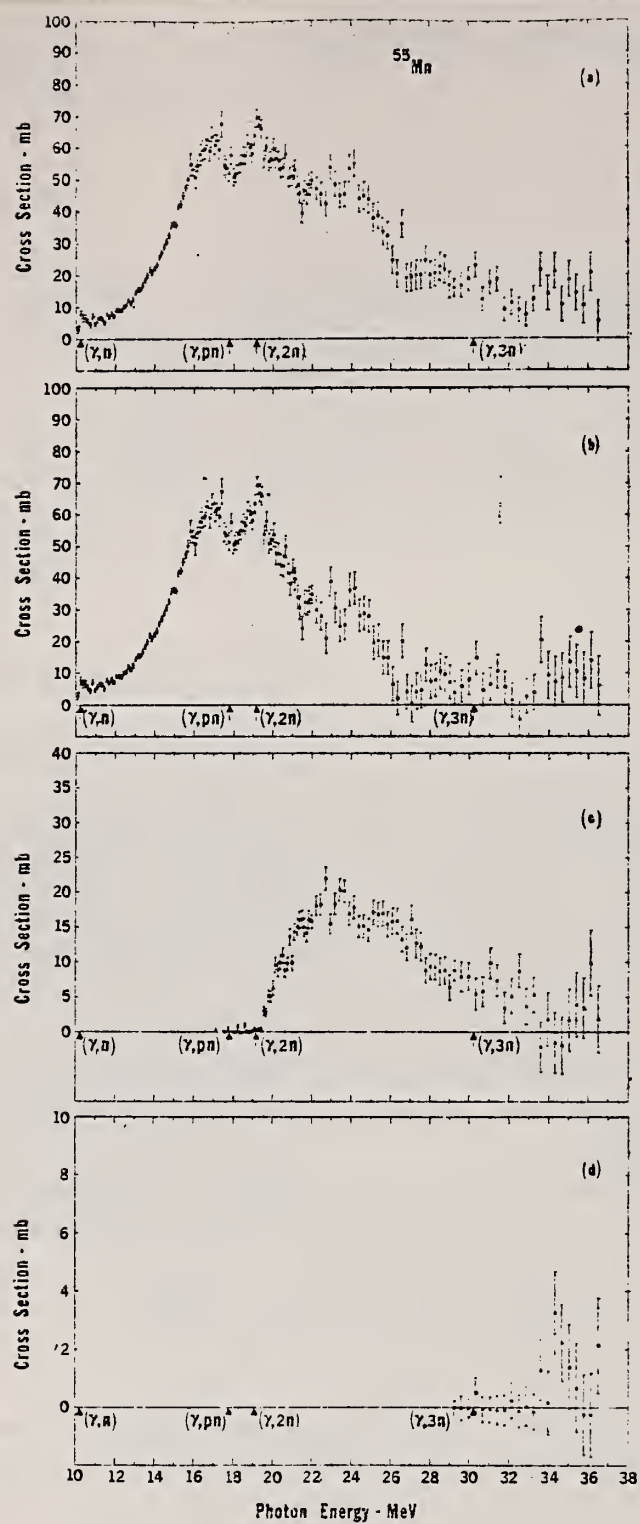


Figure 1. Photoneutron cross sections of ^{55}Mn . Thresholds are indicated by arrows.
 (a) Total photoneutron cross section: $\sigma[(\gamma,n) + (\gamma,pn) + (\gamma,2n) + (\gamma,3n)]$;
 (b) $\sigma[(\gamma,n) + (\gamma,pn)]$; (c) $\sigma(\gamma,2n)$; (d) $\sigma(\gamma,3n)$.

REF.

R.F. Barrett, J.R. Birkelund, B.J. Thomas, K.S. Lam, and H.H. Thies
Nucl. Phys. A210, 355 (1973)

ELEM. SYM.	A	Z
Mn	55	25

METHOD	REF. NO.
	73 Ba 20

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NOX	THR- 27	C	10- 27	BF3-I		4PI

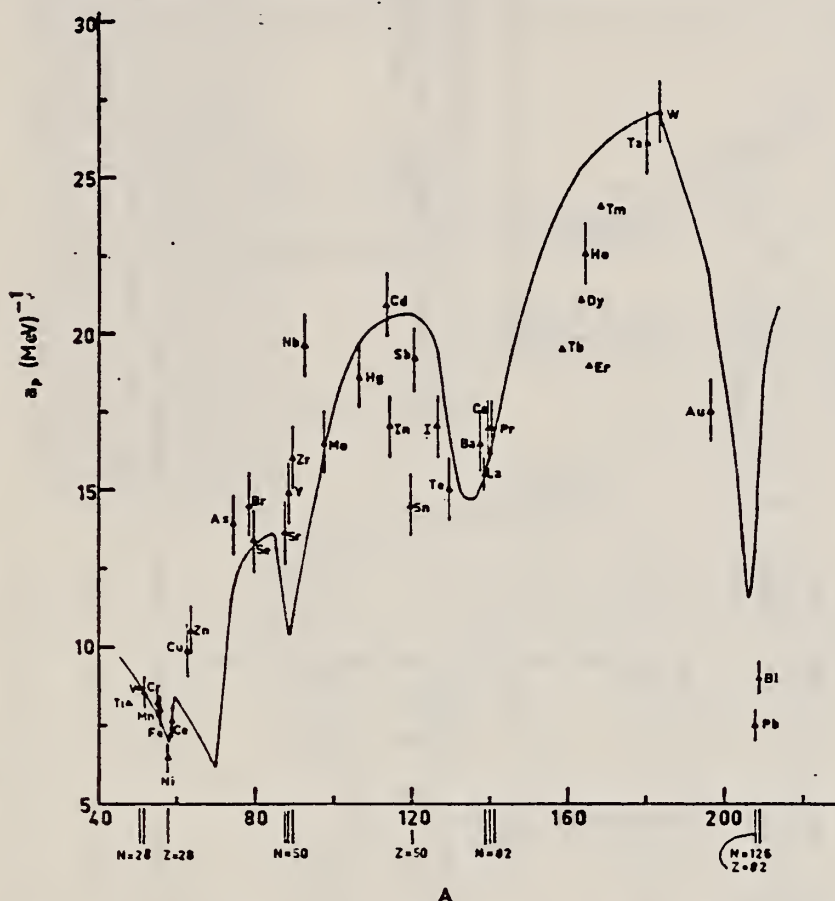


Fig. 12. Experimental values of the level density parameter a_p (Fermi gas formula plus pairing correction) versus atomic number A . The continuous curve is a least-squares fit to the data of a theoretical calculation from Newton ¹⁵).

- 1 H. Baba and S. Baba, Japan Atomic Energy Research Institute report JAERI-1183 (1969).
- 2 H. Baba, Nucl. Phys. A159, 625 (1970).
- 15 T.D. Newton, Can. J. Phys. 34, 804 (1956).

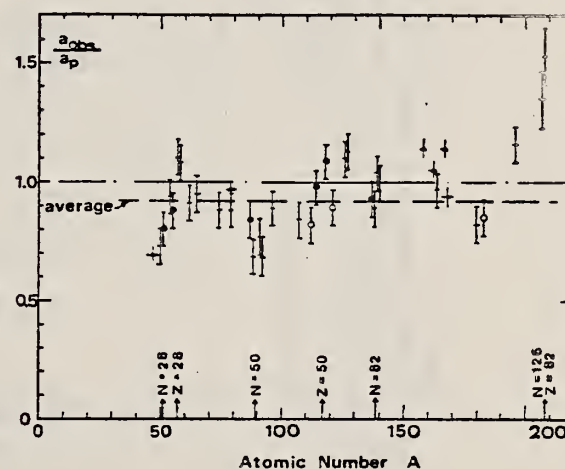


Fig. 15. Ratio a_{obs}/a_p versus atomic number A . Here a_{obs} is the level density parameter taken from the neutron resonance work of refs. ^{1,2}), and a_p is the level density parameter derived from the present (γ, n) work. Filled circles represent points where nuclei in the neutron resonance and in the (γ, n) experiment were the same. Open circles represent points where the respective nuclei were approximately matched. Triangles represent points which are based on measurement of neutron mean energies at two bremsstrahlung energies only.

(over)

TABLE 3

Comparison of experimental and theoretical data on nuclear level densities with Fermi gas formulae, and comparison of nuclear level density parameters from (γ, n) and n -resonance absorption experiments

Target	N (residual nucleus) ^{a)}	Goodness of fit ^{b)}	$E_0(24)$ (MeV) ^{c)}	T (MeV) ^{d)}	a_p (MeV ⁻¹) ^{e)}	a_{exp} (MeV ⁻¹) ^{f)}	a_{exp}/a_p
Ti ^{g)}	23 8%		1.93		8.1- ⁴⁷ Ti	6.41- ⁴⁷ Ti	0.79
	24 8%						
	25 73%						
	26 5%						
	27 5%						
V ^{g)}	27 100%		1.96		8.7- ⁵⁰ V	6.35- ⁵¹ V	0.73
Cr	25 4%	P	1.89		8.6- ⁵¹ Cr	6.9- ⁵¹ Cr	0.80
	27 84%						
	28 10%						
	29 2%						
Mn	29 100%	V.P.	2.1		8.2- ⁵⁴ Mn	7.82- ⁵⁶ Mn	0.94
Fe	27 6%	F	1.96		8.0- ⁵⁵ Fe	7.06- ⁵⁵ Fe	0.88
	29 92%						
	30 2%						
Co	31 100%	P	2.12		7.7- ⁵⁸ Co	8.35- ⁶⁰ Co	1.08
Ni	29 68%	V.P.	2.04	1.4	6.5- ^{57,7} Ni	7.19- ⁵⁹ Ni	1.10
(Z = 28)	31 26%						
	32 1%						
	33 4%						
	35 1%						
Cu	33 69%	V.P.	1.78	1.0	9.8- ⁶² Cu	8.90- ⁶⁴ Cu	0.91
	35 31%						
Zn	33 49%	F	1.61		10.5- ^{64,4} Zn	10.0- ⁶⁵ Zn	0.95
	35 28%						
	36 4%						
	37 19%						
As	41 100%	V.P.	1.44		14.5- ⁷⁴ As	12.81- ⁷⁶ As	0.88
Se ^{g)}	41 9%		1.39		13.3- ⁷⁸ Se	12.8- ⁷⁸ Se	0.97
	42 8%						
	43 24%						
	45 50%						
	47 9%						
Br	43 45%	V.P.	1.41		14.5- ⁷⁹ Br	12.69- ⁸⁰ Br	0.88
	45 49%						
Sr	47 10%	F	1.31		13.6- ⁸⁷ Sr	11.4- ⁸⁷ Sr	0.84
	48 7%						
	49 83%						

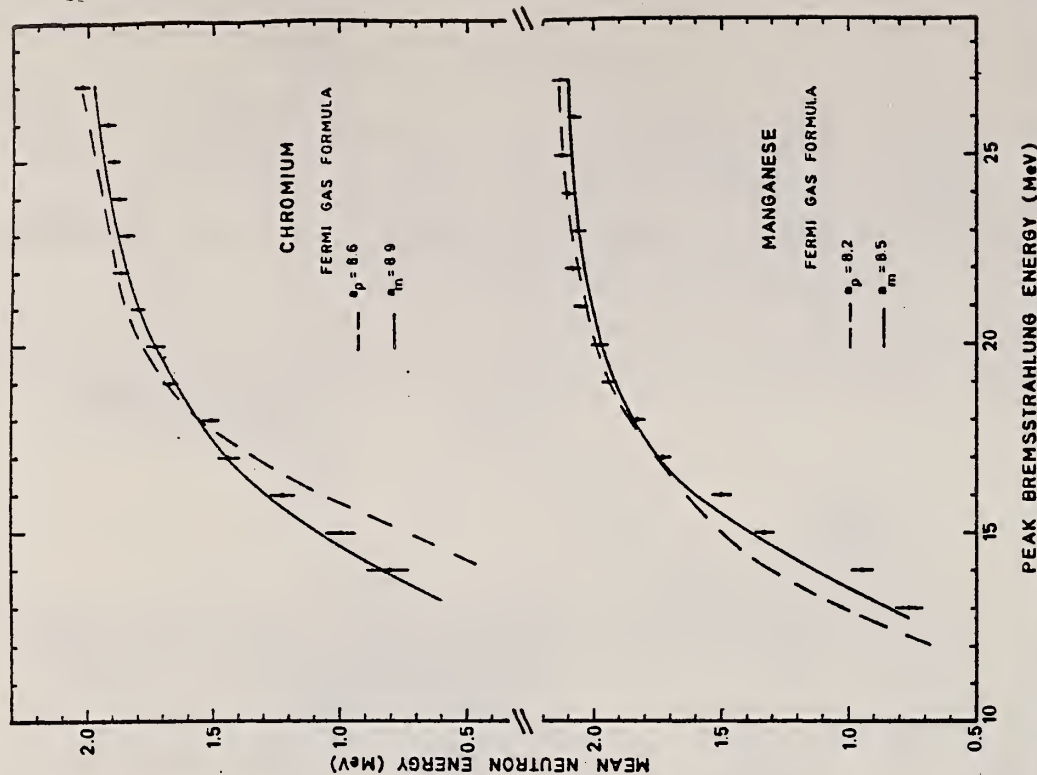


Fig. 5. Variation of photon neutron mean energy with peak bremsstrahlung energy, for chromium and manganese: experimental and calculated results.

- ^{a)} Neutron numbers and abundances of respective residual nuclei in (γ, n) experiments.
^{b)} These give an assessment of the goodness of fit of a calculated \bar{E}_n versus E_0 curve to the observed data, using the Fermi gas level density formula both without and with pairing corrections.
^{c)} Bremsstrahlung photon neutron mean energies \bar{E}_n for peak bremsstrahlung energy $E_0 = 24$ MeV.
^{d)} Nuclear temperature from fit with constant-temperature formula.
^{e)} Level density parameter a_p derived from the present (γ, n) experiment, using a Fermi gas formula plus pairing correction, and corresponding residual nucleus (the atomic weight shown is the weighted average of atomic weights of the respective isotopes present).
^{f)} As column T , but using data on n -resonance absorption from refs. 1, 2.
^{g)} Measurements of $\bar{E}_n(E_0)$ for these nuclei were made only for $E_0 = 21, 23$ and 24 MeV.

REF. H.G. De Carvalho, J.B. Martins, O.A.P. Tavares, V. Di Napoli,
F. Salvetti
PICNS-73, 983 (1973)

ELEM. SYM.	A	Z
Mn	55	25

METHOD

REF. NO.

73 Ca 8

hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	10-999	C	300-999	ACT-I		4PI
G,3N	ABY	31-999	C	300-999	ACT-I		4PI
G,4N	ABY	33-999	C	300-999	ACT-I		4PI

(G,3N) ISO YLD, ANAL 79D11

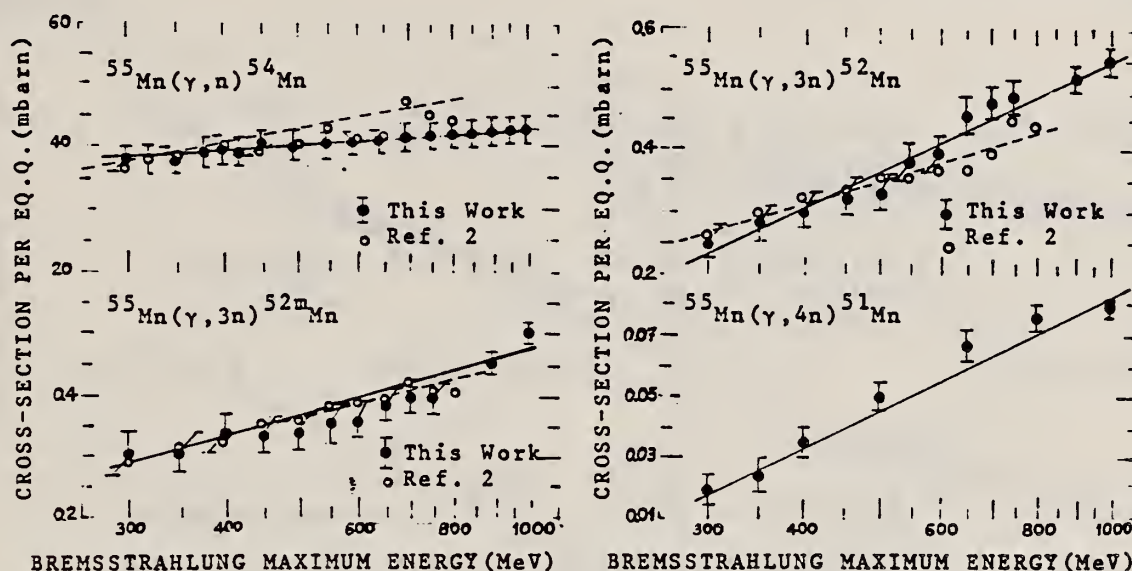


FIG. 1

FIG. 2

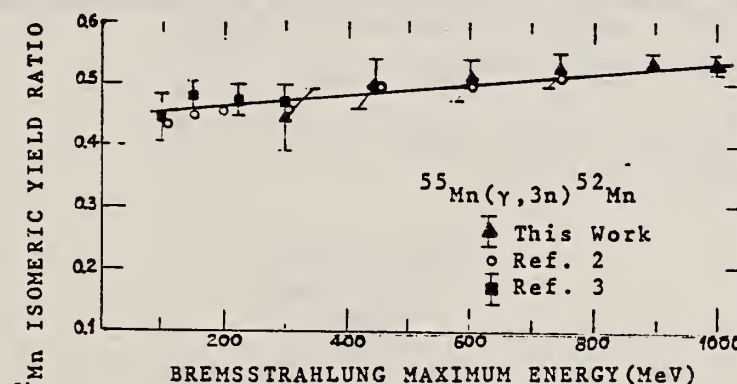


FIG. 3

² G. Anderson, B. Forkman, B. Friberg; Annual Report 1968, Lund Institute of Technology, Lund University, NP 6901, Sect. 4b (1969).

³ W.B. Walters and J. P. Hummel, Phys. Rev. 150, 867 (1966).

REF.

H. G. de Carvalho, J. B. Martins, O. A. P. Tavares,
V. di Napoli, F. Salvetti
PICNS-73, Vol. II, 983 (1973)

ELEM. SYM.

A

Z

Mn

55

25

METHOD

REF. NO.

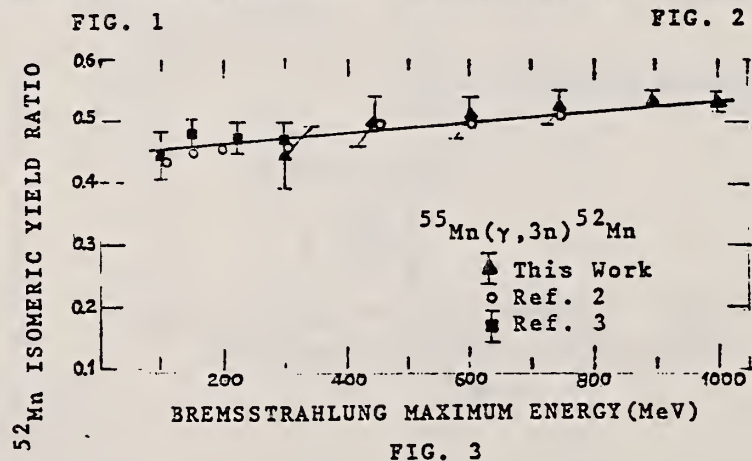
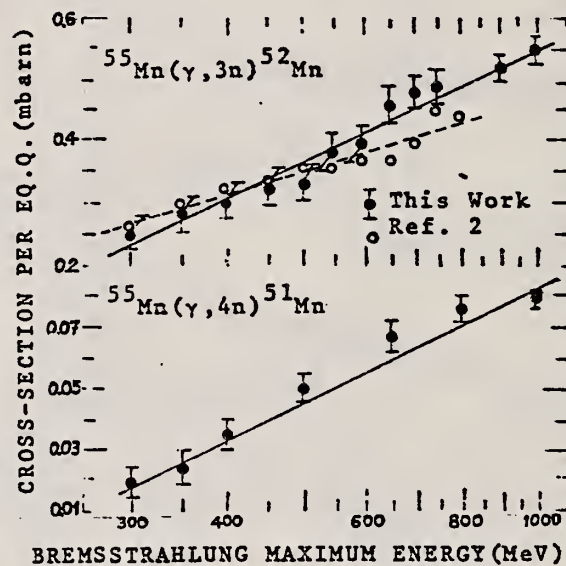
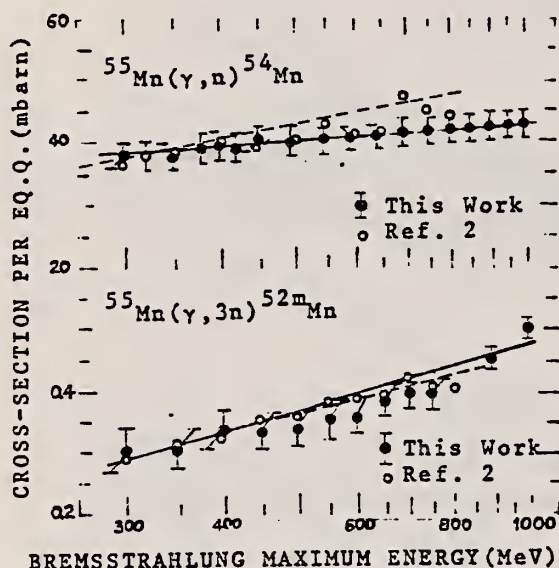
73 De 7

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N *	ABY	THR*	C	*	ACT-I		4PI
G,3N **	ABY	THR*	C	*	ACT-I		4PI
G,4N *	ABY	THR*	C	*	ACT-I		4PI

* E IN GEV

** 1 GEV ISOMER RATIO



REF.

M. Eriksson and G. G. Jonsson
PICNS-73, Vol. II, p.995 (1973) Asilomar

ELEM. SYM.

A

Z

Mn

55

25

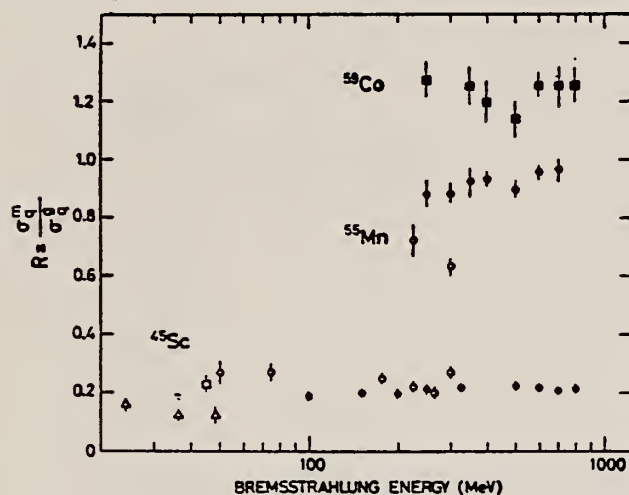
METHOD

REF. NO.

73 Er 1

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SPL	NGX	0-800	C	100-800	ACT-I		4PI

SG-44 ISOMER RATIO

Isomeric yield ratio,
 $^{44}\text{Sc}^m(6+)/^{44}\text{Sc}^g(2+)$,
 versus bremsstrahlung
 end point energy.

●, ■ this work, Δ ref 1,
 ○ ref 2, □ ref 3.

¹J.R. Tatarczuk and H.A. Medicus, Phys. Rev. 143 (1966) 818.

²W.B. Walters and J.P. Hummel, Phys. Rev. 150 (1966) 867.

³R. Völpe, Nucl. Phys. A182 (1972) 311.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, NA24	ABY	THR-999	G	100-999	ACT-I		4PI

999=1 GEV

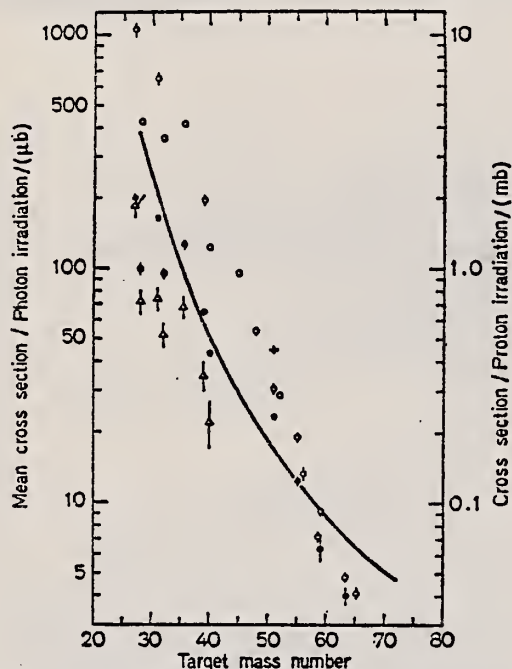


Fig. 7. Mean cross sections for ^{24}Na production as a function of target mass number. Present work filled circles. Noga *et al.* [3] open triangles, Kumbartzki *et al.* [13] cross and Korteling *et al.* [1] 400 MeV protons open circles. The solid line gives the mean cross sections calculated by Jonsson *et al.* [17]

¹Korteling, R.G. *et al.*, J. Inorg. Nucl. Chem. 29, 2863 (1967).

³Noga, V.I. *et al.*, Sov. J. Nucl. Phys. 9, 637 (1969).

¹³Kumbartzki, G. *et al.*, Nucl. Phys. A176, 23 (1971).

¹⁷Jonsson, G.G. *et al.*, LUNP7212, Oct. 1972, to be published in Physica Scripta.

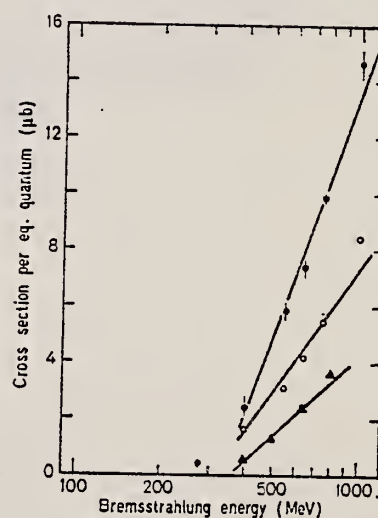


Fig. 6

Fig. 6. The determined yields for the reactions $^{55}\text{Mn} \rightarrow ^{24}\text{Na}$ (filled circles), $^{59}\text{Co} \rightarrow ^{24}\text{Na}$ (open circles) and $^{63,65}\text{Cu} \rightarrow ^{24}\text{Na}$ (filled triangles)

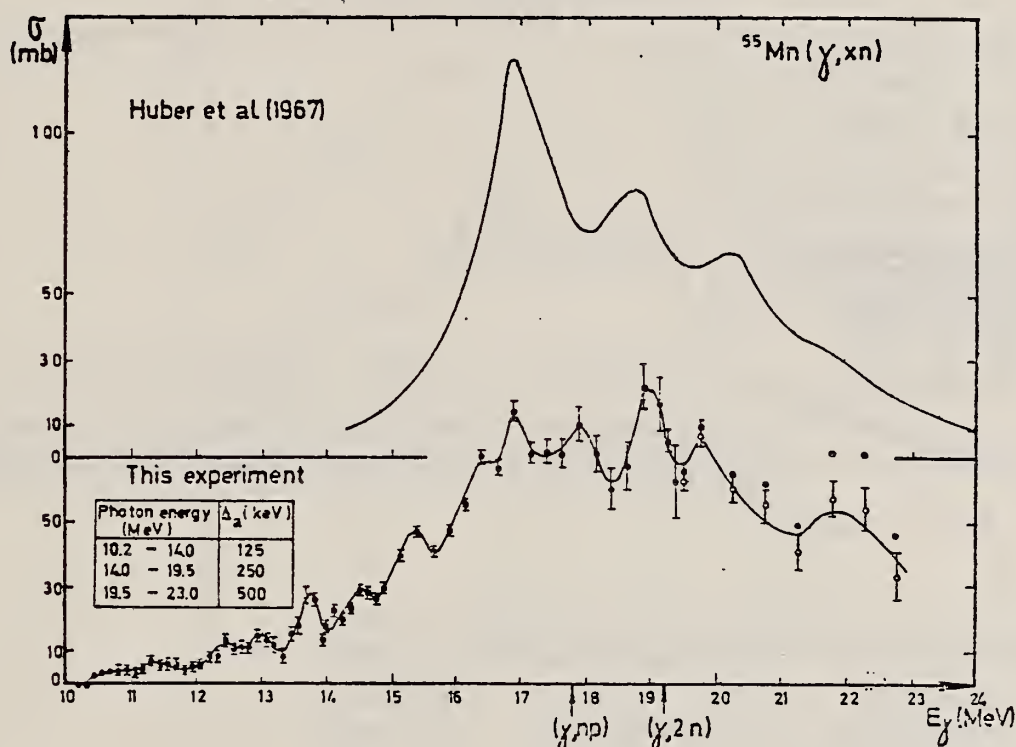
REF. R. E. Van de Vyver, R. Carchon, J. Devos, C. Van Deynse
and H. Ferdinande
PICNS-73, Vol.I, p. 543 Asilomar

ELEM. SYM.	A	Z
Mn	55	25

METHOD

REF. NO.	hmg
73 Va 5	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	10- 23	C	10- 23	BF3-I		4PI



References :

- 1) M.G. Huber, M. Danos, H.J. Weber and W. Greiner, Phys.Rev. 155 (1967) 1073

REF.			R. Carchon, J. Devos, R. Van De Vyver, C. Van Deynse, and H. Ferdinande Nucl. Phys. <u>A223</u> , 416 (1974)			ELEM. SYM.		A	Z
						Mn		55	25
METHOD						REF. NO.			
						74 Ca 6			egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE		
			TYPE	RANGE	TYPE	RANGE			
G,XN	ABX	10- 23	C	10- 23	BF3-I		4PI		

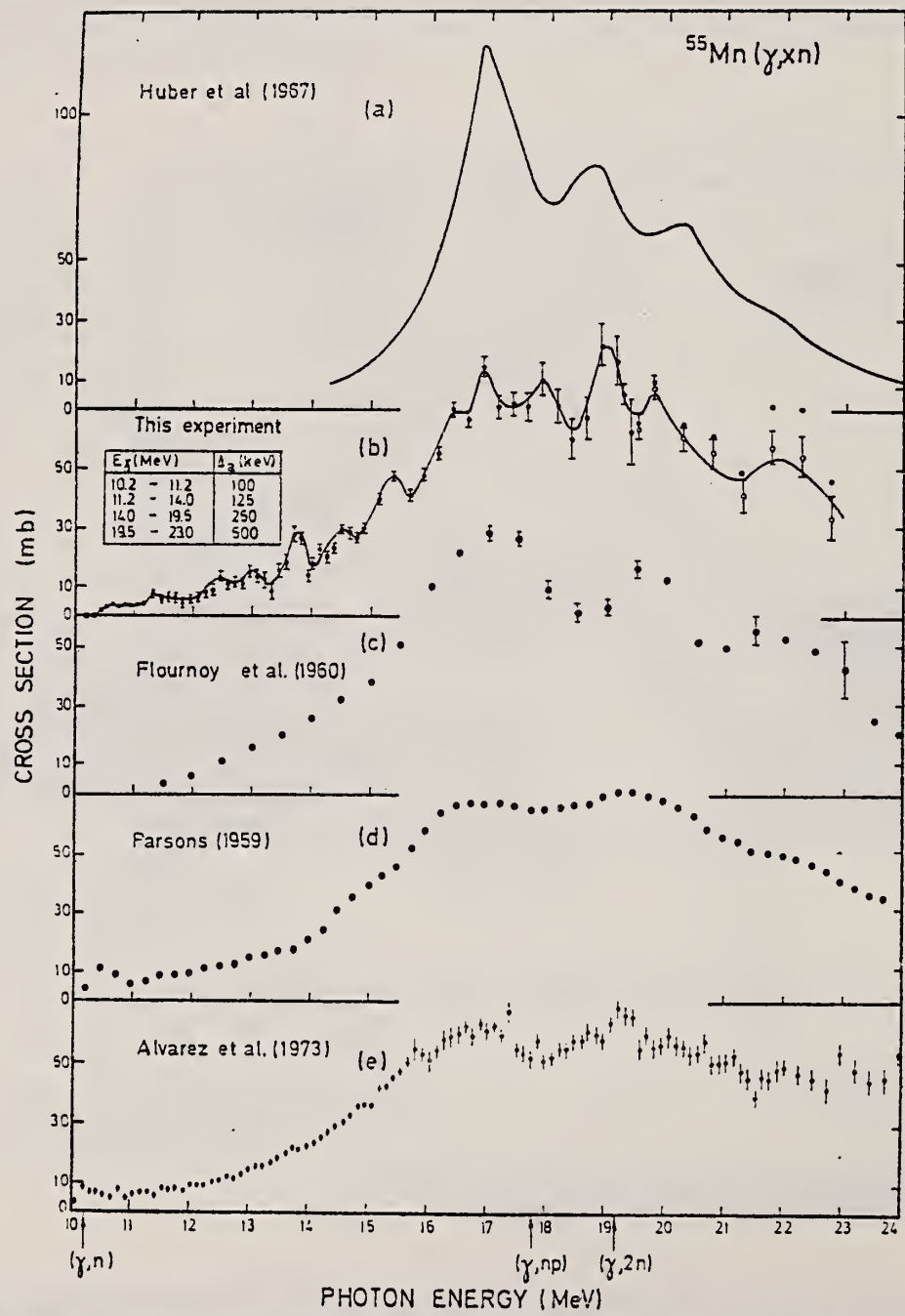


Fig. 1. Comparison of the present total photoneutron cross section for ⁵⁵Mn with previous measurements and with the DCM theory. In part (b) the open circles are the cross section values corrected for multiplicity.

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		
74 Di 8		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, 3N	ABY	THR* 1	C	100* 1	ACT-I		4PI

*1=1 GEV, ISOMER YLD

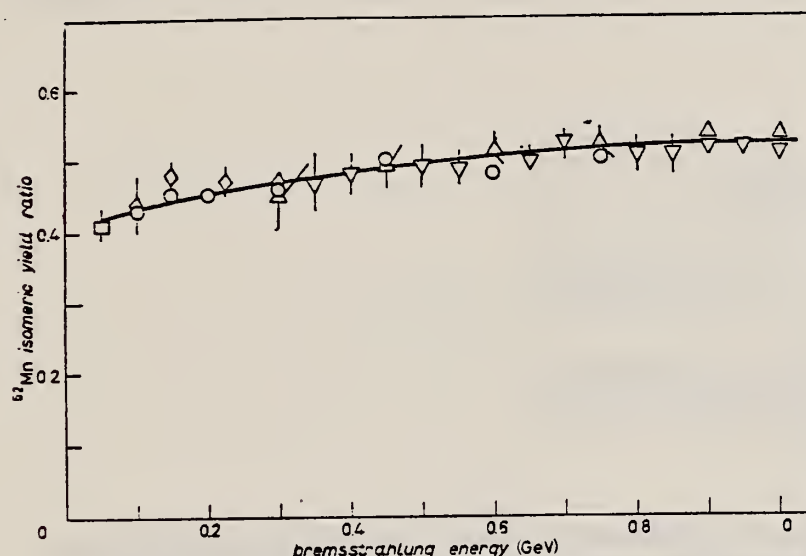


Fig. 1. - Experimental values of the isomeric-yield ratio for ^{52}Mn vs. the bremsstrahlung maximum energy. Square: ref. (1), rhombs: ref. (2), circles: ref. (3), triangles: ref. (4), reversed triangles: present work. The smoothed curve is a best fit to the experimental points in the energy range from 40 MeV up to 1 GeV.

- ³W.B. Walters et al., Phys. Rev. 150, 867 (1966).
⁴R. Volpel: Nucl. Phys. 182A, 411 (1972).
⁵G. Andersson: U. of Lund Report No. LUNP 6901 (1969), p. 11 unpublished.
⁶H.G. DeCarvalho et al.: Proc. Intnat'l Conf. Photo. Reac. & Applic. Pacific Grove, Cal. Sect. 8C5-1 (73).

TABLE II. - Cross-sections per equivalent quantum and isomeric-yield ratio for the photo-production of $^{52}\text{Mn}^g$ and $^{52}\text{Mn}^m$ from ^{55}Mn .

Bremsstrahlung energy (GeV)	σ_0 (mb)		Isomeric-yield ratio
	$^{55}\text{Mn}(\gamma, 3n)^{52}\text{Mn}^g$	$^{55}\text{Mn}(\gamma, 3n)^{52}\text{Mn}^m$	
0.35	0.28 ± 0.03	0.32 ± 0.03	0.47 ± 0.03
0.40	0.30 ± 0.03	0.33 ± 0.03	0.48 ± 0.03
0.50	0.33 ± 0.03	0.34 ± 0.03	0.49 ± 0.03
0.55	0.38 ± 0.02	0.39 ± 0.02	0.49 ± 0.02
0.65	0.46 ± 0.02	0.46 ± 0.02	0.50 ± 0.02
0.70	0.48 ± 0.02	0.44 ± 0.02	0.52 ± 0.02
0.80	0.49 ± 0.02	0.47 ± 0.02	0.51 ± 0.02
0.85	0.50 ± 0.01	0.48 ± 0.02	0.51 ± 0.02
0.90	0.52 ± 0.01	0.48 ± 0.01	0.52 ± 0.01
0.95	0.54 ± 0.01	0.50 ± 0.01	0.52 ± 0.01
1.00	0.55 ± 0.01	0.53 ± 0.01	0.51 ± 0.01

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.	74 Te 1	
	egf	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	7	D	4- 8	SCD-D		DST

7=7.491

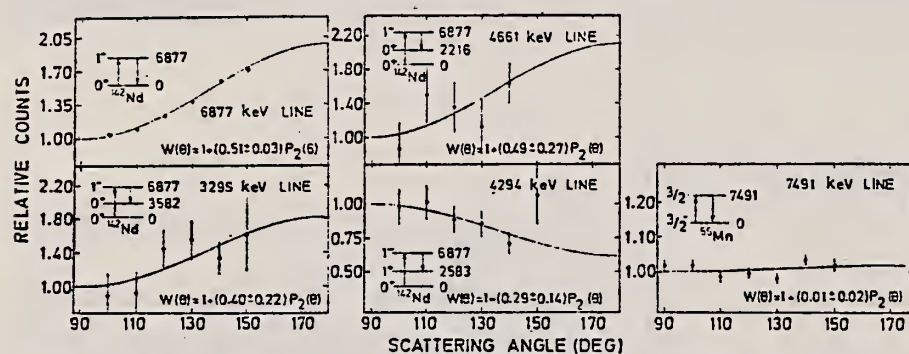


Fig. 5. Angular distributions of elastically scattered γ -lines from ^{55}Mn and ^{142}Nd . The distributions of three inelastic γ -lines from ^{142}Nd are also shown. The solid lines have the form $W(\theta) = 1 + A_2 P_2(\cos \theta)$ and are least squares fits to the experimental distribution. In each case the corresponding γ - γ cascade is indicated.

TABLE 2

Measured angular distribution coefficients A_2 , the ratios $N_{||}/N_{\perp}$, the spins and parities of the ground and the resonance levels, J_0^π and J_r^π , and the character of the ground state transition.

Scatterer	E_γ (keV)	A_2	$N_{||}/N_{\perp}$	J_0^π	J_r^π	Transition
^{55}Mn	7491	0.01 ± 0.02	1.00 ± 0.02	$\frac{1}{2}^-$	$\frac{3}{2}$	
^{140}Ce	5660	0.51 ± 0.02	1.14 ± 0.04	0^+	1^-	E1
^{141}Pr	6877	0.11 ± 0.02	0.95 ± 0.03	$\frac{1}{2}^+$	$\frac{3}{2}^+$	M1
^{142}Nd	6877	0.51 ± 0.03	1.10 ± 0.04	0^+	1^-	E1
^{202}Hg	4922	0.51 ± 0.02	1.18 ± 0.03	0^+	1^-	E1
^{209}Bi	5603	0.06 ± 0.02	0.97 ± 0.02	$\frac{1}{2}^-$	$\frac{1}{2}^-$	M1

TABLE 4

Values of Γ , Γ_0 and the energy separation δ (between the incident γ -line and the resonance level) as obtained from the analysis of the various experiments

Scatterer	E_γ (keV)	Γ (meV)	Γ_0 (meV)	δ (eV)	D (eV)	K_{E1} (10^{-9} MeV^{-3})	K_{M1} (10^{-9} MeV^{-3})
^{55}Mn	7491	450 ± 250	80 ± 40	17 ± 1			
^{140}Ce *)	5660	13 ± 3	12 ± 2	4.7 ± 0.3	6800	0.33	
^{141}Pr *)	6877	85 ± 35	17 ± 9	6.7 ± 1.5	450		116
^{142}Nd *)	6877	340 ± 40	270 ± 20	12.4 ± 0.3	1200	26	
^{202}Hg	4922	300 ± 50	260 ± 20	4.2 ± 0.5	19000	3.4	
^{209}Bi *)	5603	950 ± 200	950 ± 200	13 ± 1	34000		160

The radiative strengths K_{E1} and K_{M1} are also given. The level spacing D refers to the excitation energy of the resonance level E_γ .

*) These values are slightly different from those of ref. 8) and were obtained from a renewed analysis of the experimental results.

METHOD

REF. NO.

75 Er 2

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SC44	ABY	THR-800	C	250-800	ACT-I		4PI

ISOMER RATIO

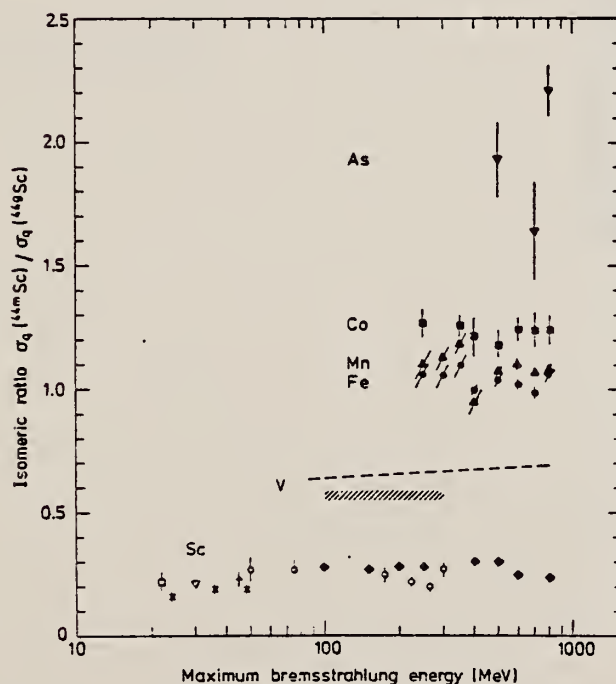


Fig. 6. Isomeric ratio $\sigma_q(^{44m}\text{Sc})/\sigma_q(^{44g}\text{Sc})$ versus bremsstrahlung end-point energy for the different targets. Sc target: \blacklozenge - this work, \square - ref. ¹⁵, \times - ref. ¹⁶, ∇ - ref. ¹⁷, $+$ - ref. ¹⁸, \circ - ref. ¹⁹; V target: dashed curve - ref. ²⁰, dashed area - ref. ²¹; Fe target: \bullet - this work; Mn target: \blacktriangle - this work; Co target: \blacksquare - this work; As target: \blacktriangledown - this work.

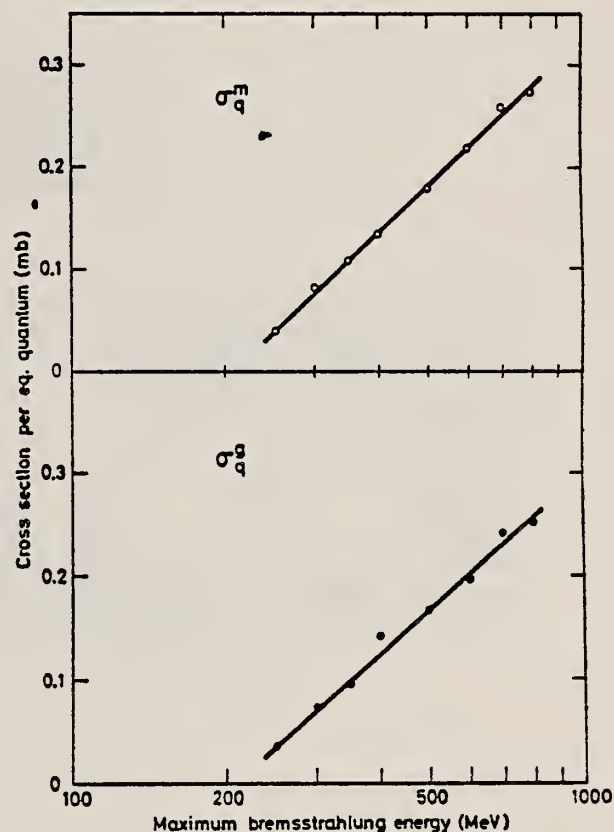


Fig. 3. Yield curves for the reaction $^{55}\text{Mn}(\gamma, 4p7n)^{44}\text{Sc}$.

(over)

TABLE 2
Comparison between experimental and calculated cross sections and isomeric ratios

Target	$\bar{\sigma}_{exp}$ (mb) 250-800 MeV	σ_{MC} (mb) 400 MeV	$\bar{\sigma}_{SE}$ (mb) 250-800 MeV	$\sigma(m)/\sigma(g)_{exp}$ 250-800 MeV	$\sigma(m)/\sigma(g)_{calc}$ 400 MeV
⁴³ Sc	≈ 0.5	0.58 ± 0.05		≈ 0	0.05
⁵¹ V	≈ 0.5	0.48 ± 0.05	0.47	0.7	0.72
⁵⁵ Mn	0.40 ± 0.14	0.59 ± 0.05	0.28	1.08 ± 0.04	1.04
Fe	0.40 ± 0.14		0.26	1.00 ± 0.05	
⁵⁹ Co	0.26 ± 0.10	0.34 ± 0.04	0.18	1.26 ± 0.06	1.12
		$0.65 \pm 0.07^*)$			$1.15^*)$
⁷⁵ As		0.01 ± 0.01	0.044	1.9 ± 0.3	

*) 325 MeV.

- 15) S. A. Steinberg, B. Sc. thesis, Univ. of Illinois, 1963, unpublished (value taken from ref. '7))
- 16) J. R. Tatarczuk and H. A. Medicus, Phys. Rev. 143 (1966) 818
- 17) T. Kato and Y. Oka, Talanta 19 (1972) 515
- 18) R. Völpe, Nucl. Phys. A182 (1972) 411
- 19) W. B. Walters and J. P. Hummel, Phys. Rev. 150 (1966) 867
- 20) B. Bülow, Lund, private communication (preliminary results)
- 21) R. A. Meyer, thesis, Univ. of Illinois, 1963, unpublished

REF.

A. S. Danagulyan, N. A. Demekhina
Yad. Fiz. 24, 681 (1976)
Sov. J. Nucl. Phys. 24, 355 (1976)

ELEM. SYM.	A	Z
Mn	55	25

METHOD

REF. NO.

76 Da 4

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,NA24	ABX	THR* 5	C	2* 5	ACT-I		4PI

*ENERGY, GEV

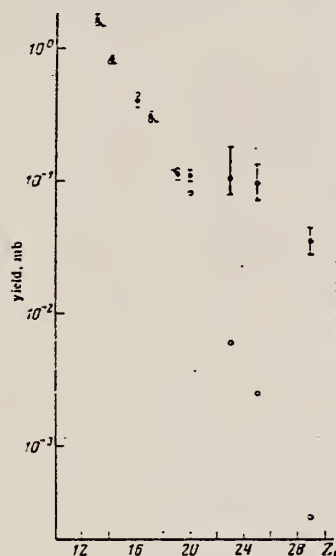


FIG. 2. Yield values and theoretical values according to the modified Rudstam formula as a function of the target charge number Z_1 . Points: ●—experiment, ○—theory.

TABLE I. Experimental yields and reaction cross sections obtained in the measurements at the Erevan electron accelerator.

Target nucleus	Reaction yield, mb					Reaction cross section, mb
	$E_T \text{ max, GeV}$					
	2	3	4	4.5	5	
^{27}Al	0.81 ± 0.08	0.87		0.97		0.07213 ± 0.0346
^{28}Si	0.27 ± 0.02	0.23		0.29		0.0257 ± 0.013
^{31}S	0.24 ± 0.02	0.22		0.27		0.0323 ± 0.0135
Cl	0.28 ± 0.03	0.30		0.28		—
^{39}K	0.1 ± 0.01	0.125		0.15		0.06 ± 0.0238
^{40}Ca	0.086 ± 0.01	0.09		0.115		0.035 ± 0.0168
^{51}V	0.093 ± 0.02	0.094 ± 0.02	0.038 ± 0.02		0.082 ± 0.025	0.019
^{55}Mn	0.079 ± 0.02	0.075 ± 0.02	0.087 ± 0.017		0.088 ± 0.015	0.01078 ± 0.0056
Cu	0.029 ± 0.006	0.037 ± 0.007	0.036 ± 0.007		0.034 ± 0.007	0.00347 ± 0.0028

Note. The reaction cross sections have been calculated in the $1/E$ approximation of the bremsstrahlung spectrum.

ELEV. SYM.	A	Z
Mn	55	25
REF. NO.		egf
77 Da 3		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,SPL	ABY	THR * 5	C	2*5	ACT-I		4PI

*ENERGY, GEV

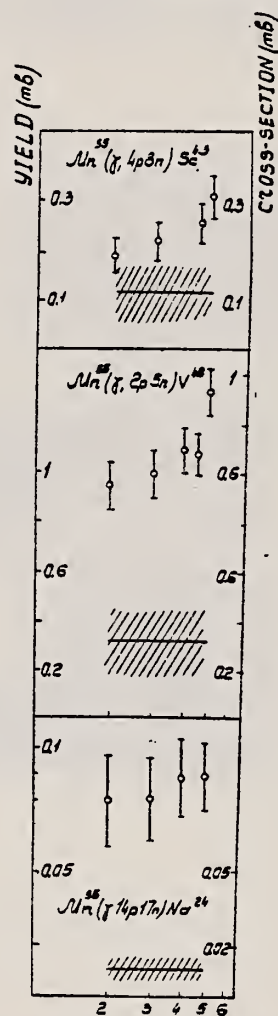


Fig. 2. Yields of some spallation reactions in ^{51}V , ^{55}Mn and Cu targets. The cross section estimates are obtained in the $1/E$ approximation for bremsstrahlung.

(over)

TABLE 2
Photospallation reaction yields (mb per eq. quantum)

Residual nuclei	Reaction yields (mb)					Reaction cross sections (mb)
	$E_{\gamma, \max} = 2 \text{ GeV}$ (exp)	3 GeV (exp)	4 GeV (exp)	5 GeV (exp)	5 GeV (cal)	
	<i>⁵⁵Mn target</i>					
⁵⁴ Mn	43	43	43	43		
⁵² Mn	0.55	0.55	0.55	0.55	1.34	
^{52m} Mn	0.48 ± 0.05	0.43 ± 0.04	0.6 ± 0.06	0.48 ± 0.05		
⁵¹ Cr	3.74 ± 0.4	3.94 ± 0.4	3.75 ± 0.4	3.9 ± 0.4	3.8	0.0253 ± 0.012
⁴⁹ Cr	0.26 ± 0.03	0.25 ± 0.03	0.26 ± 0.03	0.26 ± 0.03	0.31	
⁴⁸ Cr			0.027 ± 0.004	0.027 ± 0.005	0.04	
⁴⁸ V	0.95 ± 0.1	1.0 ± 0.1	1.1 ± 0.1	1.34 ± 0.1	1.18	0.318 ± 0.152
⁴⁸ Sc	0.1 ± 0.01	0.098 ± 0.01	0.11 ± 0.01	0.134 ± 0.01	0.167	0.0329 ± 0.016
⁴⁷ Sc	0.53 ± 0.05	0.56 ± 0.05	0.48 ± 0.05	0.55 ± 0.05	0.53	
⁴⁶ Sc	1.2 ± 0.2	1.1 ± 0.15	1.2 ± 0.2	1.2 ± 0.1	1.3	0.0687 ± 0.033
⁴⁴ Sc	0.42 ± 0.04	0.42 ± 0.04	0.55 ± 0.1	0.48 ± 0.05		0.072 ± 0.034
^{44m} Sc	0.45 ± 0.04	0.47 ± 0.04	0.42 ± 0.05	0.55 ± 0.05	0.9	0.034 ± 0.016
⁴³ Sc	0.19 ± 0.04	0.22 ± 0.04	0.26 ± 0.05	0.31 ± 0.06	0.27	0.115 ± 0.055
⁴⁴ K		0.065 ± 0.01		0.065 ± 0.01	0.04	
⁴³ K	0.208 ± 0.02	0.214 ± 0.02	0.18 ± 0.02	0.214 ± 0.02	0.14	
⁴² K	0.39 ± 0.04	0.34 ± 0.07	0.36 ± 0.07	0.34 ± 0.07	0.38	
⁴¹ Ar	0.071 ± 0.01	0.062 ± 0.01	0.082 ± 0.01	0.066 ± 0.01	0.07	0.003 ± 0.0014
³⁰ Cl		0.06 ± 0.01		0.057 ± 0.01	0.05	
³⁸ Cl		0.08 ± 0.02		0.11 ± 0.02	0.15	
²⁴ Na	0.079 ± 0.02	0.079 ± 0.02	0.087 ± 0.017	0.088 ± 0.015	0.033	0.0117 ± 0.005

Calculated values are obtained using Rudstam's formula. Cross section estimates are made in the $1/E$ approximation.

REF.

H. Hirayama and T. Nakamura
Nucl. Inst. Meth. 147, 563 (1977)

ELEM. SYM.

A

Z

55

Mn

25

METHOD

REF. NO.

77 Hi 5

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABI	10-30	C	18-30	ACT-I		4PI
		(10.2)					

THICK BREMS TARGET

The integral experiment for a sensitivity check of photonuclear cross section data of C, Mn, Fe, In and Au was performed by using the bremsstrahlung produced in a thick iron target by 18, 22, 26 and 30 MeV electrons from a linear accelerator. The cross section data measured by the activation method showed better results for all incident electron energies than those by the photoneutron method, because the latter include the competing (γ, np) reaction above its threshold energy. It is necessary to obtain the cross section data of (γ, n), (γ, np), ($\gamma, 2n$), ($\gamma, p2n$) reactions etc., separately by the activation method.

The effective energy range and effective cross section in the giant resonance region were determined for C, Mn, Fe and Au. By using these quantities, the gross structure of the bremsstrahlung spectrum was obtained in good agreement with the theoretical calculation.

TABLE 3

Ratio of measured and calculated saturated activities at 9° , $R_i = A_i^{\text{exp}}/A_i^{\text{cal}}$.

Reaction	Reference	Detector	Electron energy				Threshold energy of competing (γ, np) reaction (MeV)
			18 MeV	22 MeV	26 MeV	30 MeV	
$^{12}\text{C}(\gamma, n)^{11}\text{C}$	6	ACT ^a	-	1.205	1.09	0.824	27.4
	7	BF3 ^b	-	0.757	0.931	-	
	8	BF3	-	1.492	1.189	0.914	
	9	BF3	-	1.418	1.159	-	
$^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$	10	BF3	0.575	0.810	0.598	-	17.8
	11		0.595	0.875	0.654	0.609	
$^{54}\text{Fe}(\gamma, n)^{53}\text{Fe}$	12	ACT	0.542	0.783	0.722	1.12	20.9
$^{115}\text{In}(\gamma, n)^{114\text{m}}\text{In}$	13	BF3	0.448	0.511	-	-	15.9
	14	BF3	0.603	0.672	0.586	1.00	
$^{115}\text{In}(\gamma, \gamma)^{115\text{m}}\text{In}$	15	ACT	0.829	1.00	0.852	0.995	
$^{197}\text{Au}(\gamma, n)^{196}\text{Au}$	16	BF3	0.743	0.553	0.529	-	13.7
	17	BF3	0.842	0.628	0.608	0.476	

^a ACT: measurement of radioactivity of the target.^b BF3: BF₃ neutron counter with moderator.

(OVER)

TABLE 4
Effective cross section and effective energy range.

Reaction	Effective energy range (MeV)	Effective cross section (mb)			Average
		22 MeV	26 MeV	30 MeV	
$^{12}\text{C}(\gamma, n)^{11}\text{C}$	20.5-24.5	—	5.98	5.28	5.63 ± 0.35
$^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$	15.0-20.5	—	56.2	52.7	54.5 ± 1.7
$^{54}\text{Fe}(\gamma, n)^{53}\text{Fe}$	17.0-24.0	—	33.6	47.9	40.8 ± 7.2
$^{197}\text{Au}(\gamma, n)^{196}\text{Au}$	12.5-15.0	553.5	532.5	415.0	500 ± 85

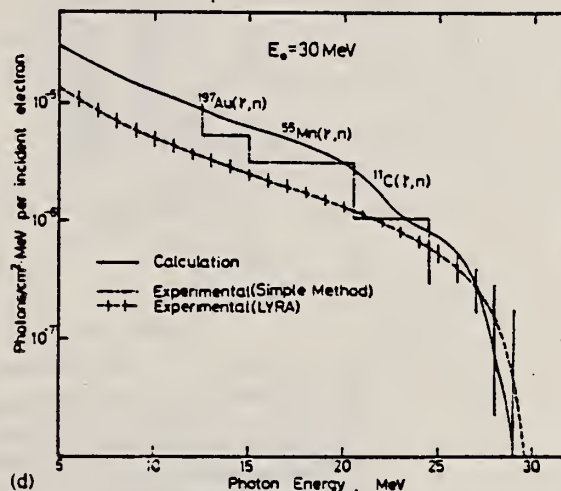
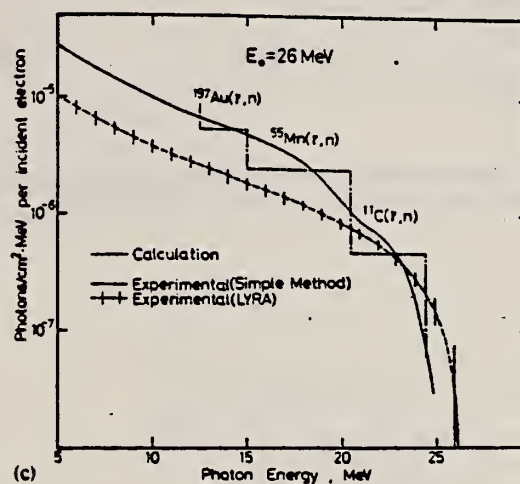
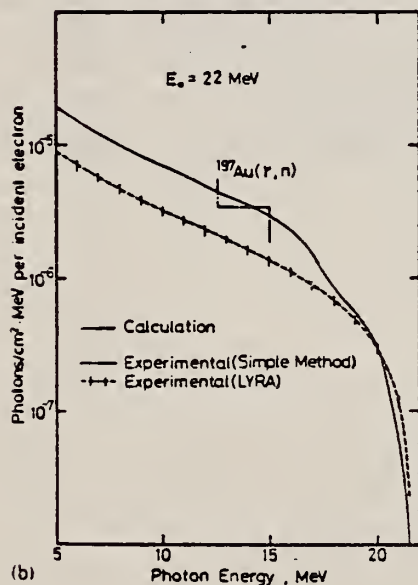
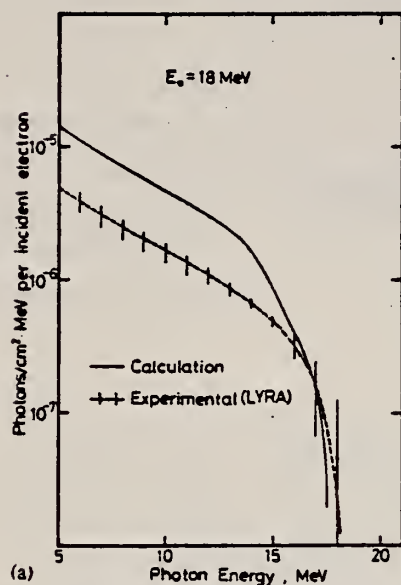


Fig. 3. Comparison of experimental and calculated bremsstrahlung spectra emitted from an iron target in the 9° direction by (a) 18 MeV electrons, (b) 22 MeV electrons, (c) 26 MeV electrons, (d) 30 MeV electrons.

REF. Z. Berant and R. Moreh
Phys. Lett. 73B, 142 (1978)

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		
78 Be 6		rs

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	ABX	6- 10	D	6- 10	SCD-D		140
G,G	ABX	11	D	11	NAI-D		140

The elastic differential scattering cross section from ^{55}Mn has been measured at $\theta = 140^\circ$ with $E_\gamma = 5.5-11.4$ MeV photons. Evidence for destructive interference between nuclear resonance (NR) scattering and nuclear Thomson (NT) scattering has been obtained.

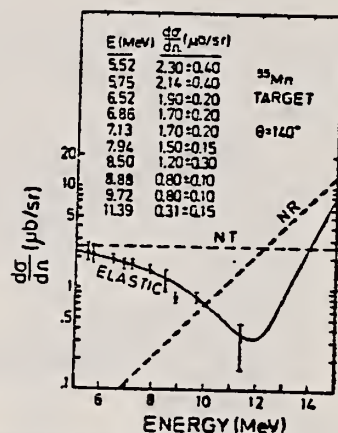


Fig. 1. Differential cross section ($\mu\text{b/sr}$) for elastic scattering of photons from ^{55}Mn at $\theta = 140^\circ$. The solid curve represents the values obtained by including the incoherent and coherent contributions of the NT, NR and D scattering amplitudes. The dashed curves denoted NT and NR represent the pure contributions of nuclear Thomson and nuclear resonance scattering, respectively.

REF. A.S. Danagulyan, N.A. Demekhina
Yad. Fiz. 27, 877 (1978)
Sov. J. Nucl. Phys. 27, 466 (1978)

ELEM. SYM.	A	Z
Mn	55	25

METHOD					REF. NO.	
					78 Da 13	hg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,4P7N	ABY	THR*5	C	2*5	ACT-D	

We discuss data concerning the ratios of the yields of different isomeric states in the elements ^{44}Sc and ^{52}Mn . Experimental results are presented for measurement of the yields of ^{44}Sc and ^{52}Mn in disintegration of targets of ^{51}V , ^{55}Mn , and Cu by photons with energies from 2 to 5 GeV; theoretical values of yields for these elements were obtained by means of the five-parameter Rudstam formula. The pattern of formation of high-spin states in photodisintegration reactions is discussed in terms of the cascade-evaporative model.

*GEV, ISOMER YLD

PACS numbers: 25.20. + y, 27.40. + z

TABLE I.

Type of target	Isomeric states	Yield ratio				
		Experiment				Theory
		$E_{\text{photon}} = 2 \text{ GeV}$	3 GeV	4 GeV	5 GeV	
^{51}V	^{44}Sc	0.47 ± 0.03	0.47 ± 0.03	0.44 ± 0.04	0.46 ± 0.04	1.03
	^{44}Sc	0.55 ± 0.06	0.45 ± 0.06	0.57 ± 0.07	0.56 ± 0.07	
^{55}Mn	^{44}Sc	0.45 ± 0.04	0.47 ± 0.04	0.42 ± 0.05	0.55 ± 0.05	1.3
	^{44}Sc	0.42 ± 0.04	0.42 ± 0.04	0.55 ± 0.1	0.45 ± 0.05	
^{55}Mn	^{52}Mn	0.48 ± 0.05	0.43 ± 0.04	0.6 ± 0.06	0.48 ± 0.05	1.34
	^{52}Mn	0.55	0.55	0.55	0.55	
Cu	^{44}Sc	0.25 ± 0.03	0.27 ± 0.03	0.26 ± 0.026	0.24 ± 0.03	0.35
	^{44}Sc	-	0.13 ± 0.01	0.15 ± 0.02	0.14 ± 0.05	
Cu	^{52}Mn	-	-	0.123 ± 0.01	-	0.55
	^{52}Mn	0.55 ± 0.05	0.47 ± 0.05	0.525 ± 0.05	0.473 ± 0.05	

TABLE II.

Type of target	Photon energy, MeV	Isomeric yield ratio	Remarks
^{51}V	65-300	0.75 ± 0.03	[11] [10] Present work
	100-800	0.58	
	2000-5000	0.87 ± 0.04	
^{55}Mn	250	0.61 ± 0.02	[7] [8]
	250-800	1.03 ± 0.05	
^{55}Mn	225	0.72	[7] [7] [8] Present work
	300	0.64	
	250-800	1.09 ± 0.04	
	2000-5000	1.02 ± 0.02	
^{59}Co	250-800	1.24 ± 0.06	[4] Present work
	2000-5000	1.84 ± 0.16	
^{71}As	250-800	1.9 ± 0.3	[8]
^{55}Mn	70	0.47	[7] [7]
	100-250	0.56	
^{55}Mn	100-300	0.83	[7] Present work
	2000-5000	1.12 ± 0.1	
^{59}Co	150	1.62	[7] Present work
	4000	4.1 ± 0.4	

ELEM. SYM.	A	Z
Mn	55	25
REF. NO.		
78Di12		hg

METHOD			REF. NO.		
			78Di12		
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G, SPL	ABY	THR-999	C	300-999	4PI
			DETECTOR		
			TYPE	RANGE	
			ACT-I		

Abstract—Cross sections per equivalent quantum, in the energy range 0.3–1.0 GeV, have been measured for spallation residuals from ^{51}V , ^{55}Mn , natural Fe, and ^{59}Co targets. Mean cross sections per photon have been deduced in this energy range and the data analysed in terms of charge-dispersion curves and mass-yield distributions. The mean cross sections per photon have also been compared with a semiempirical Rudstam's formula. A satisfactory good agreement has been found with the calculated yields within a factor of two.

YLDS 24NA TO 51CR

Table 3. Yields of radionuclides in units of μb per equivalent quantum. Manganese target

Nuclide	$E_0(\text{GeV})$					
	0.30	0.40	0.50	0.60	0.75	0.90
^{24}Na	3.0 ± 0.3	6.0 ± 0.6	8.0 ± 0.8	10.0 ± 1.0	12.0 ± 1.0	14.0 ± 1.0
^{27}Mg	5 ± 1	6 ± 1	9 ± 1	11 ± 1	13 ± 1	15 ± 1
^{28}Mg		0.5 ± 0.2	1.0 ± 0.3	1.5 ± 0.4	2.2 ± 0.5	2.8 ± 0.5
^{29}Al	15 ± 3	25 ± 5	30 ± 4	35 ± 4	45 ± 4	50 ± 4
^{30}Al	6 ± 1	10 ± 2	12 ± 2	15 ± 3	16 ± 2	18 ± 2
$^{31}\text{Cl}^m$	34 ± 7	42 ± 5	50 ± 4	55 ± 4	60 ± 4	67 ± 4
^{32}Cl	16 ± 4	28 ± 6	38 ± 8	47 ± 8	57 ± 8	65 ± 8
^{33}Cl	20 ± 4	23 ± 3	25 ± 2	28 ± 2	31 ± 2	33 ± 2
^{36}Ar	18 ± 5	28 ± 4	36 ± 4	42 ± 4	50 ± 4	56 ± 5
^{39}K	50 ± 15	76 ± 15	100 ± 17	115 ± 17	135 ± 16	150 ± 16
^{40}K	5 ± 2	15 ± 5	25 ± 6	35 ± 7	45 ± 7	50 ± 7
^{41}K	17 ± 5	19 ± 4	21 ± 4	24 ± 4	26 ± 4	30 ± 4
^{42}K	1.0 ± 0.5	1.0 ± 0.5	1.2 ± 0.5	1.4 ± 0.5	1.7 ± 0.5	2.0 ± 0.5
^{44}Ca	10 ± 3	12 ± 3	13 ± 3	15 ± 2	16 ± 2	17 ± 2
^{46}Sc	16 ± 5	17 ± 5	40 ± 7	60 ± 7	75 ± 7	90 ± 7
$^{47}\text{Sc}^m$	135 ± 15	170 ± 15	200 ± 15	215 ± 15	245 ± 15	265 ± 16
^{48}Sc	140 ± 20	170 ± 20	200 ± 20	220 ± 20	250 ± 20	270 ± 20
^{49}Sc	190 ± 40	210 ± 40	290 ± 40	350 ± 45	420 ± 45	460 ± 46
^{50}Sc	170 ± 40	180 ± 40	260 ± 45	300 ± 45	340 ± 45	380 ± 45
^{51}V	1.0 ± 0.5	2 ± 1	15 ± 4	24 ± 5	35 ± 5	50 ± 6
^{52}V	410 ± 50	470 ± 50	520 ± 50	550 ± 50	600 ± 60	650 ± 60
^{54}Cr	12 ± 3	13 ± 3	15 ± 3	17 ± 3	18 ± 3	19 ± 3
^{56}Cr	132 ± 15	144 ± 15	153 ± 15	160 ± 15	170 ± 16	176 ± 18
^{58}Cr	2000 ± 150	2150 ± 150	2250 ± 150	2340 ± 150	2450 ± 150	2530 ± 150

Table 6. Mean cross sections in the energy range 0.3–1 GeV in units of μb

Produced radio-nuclide	Target nucleus				
	Present work	Vanadium Bülow <i>et al.</i> [26]	Manganese	Iron	Cobalt
^{24}Ne	2.0 ± 0.4				
^{26}Na	16 ± 4				
^{27}Na	30 ± 2	-18 ± 2	10 ± 1	10 ± 1	7 ± 1
^{28}Mg	22 ± 2	18 ± 3	9 ± 1	10 ± 1	8 ± 1
^{29}Mg	6 ± 1	6 ± 1	2.7 ± 0.5	2.7 ± 0.5	2.2 ± 0.3
^{30}Al	58 ± 7	59 ± 4	29 ± 4	35 ± 4	25 ± 3
^{31}Al	25 ± 4	32 ± 2	11 ± 2	15 ± 2	16 ± 3
$^{32}\text{Cl}^m$	16 ± 2	14 ± 2	30 ± 4	30 ± 4	19 ± 3
^{33}Cl	75 ± 13	96 ± 5	45 ± 8	50 ± 8	37 ± 7
^{36}Ar	37 ± 7	35 ± 1	12 ± 2	19 ± 3	13 ± 2
^{39}K	65 ± 6	54 ± 2	35 ± 4	28 ± 3	12 ± 2
^{40}K	280 ± 50	243 ± 11	94 ± 17	80 ± 15	66 ± 12
^{41}K	128 ± 20	128 ± 4	43 ± 7	30 ± 5	28 ± 5
^{42}K	33 ± 12	30 ± 3	11 ± 4	10 ± 4	9.5 ± 4
^{43}K	12 ± 2	8 ± 1	1.0 ± 0.5	1.2 ± 0.5	1.0 ± 0.5
^{44}Ca	12 ± 4	15 ± 1	6.5 ± 2.4	6 ± 2	2.2 ± 0.8
^{46}Sc	104 ± 10	109 ± 6	72 ± 7	77 ± 8	52 ± 6
$^{47}\text{Sc}^m$	260 ± 30	243 ± 14	115 ± 15	100 ± 12	84 ± 10
^{48}Sc	230 ± 40	218 ± 13	116 ± 20	90 ± 16	71 ± 13
^{49}Sc	575 ± 100	605 ± 18	260 ± 45	214 ± 35	220 ± 40
^{50}Sc	457 ± 100	540 ± 33	200 ± 45	160 ± 30	127 ± 30
^{51}V	165 ± 15	138 ± 8	50 ± 5	30 ± 3	25 ± 3
^{52}V	210 ± 50	307 ± 12	200 ± 50	184 ± 45	100 ± 25
^{54}Cr	20 ± 10		7 ± 3	8 ± 4	5.0 ± 2.5
^{56}Cr	13 ± 5	16 ± 2	40 ± 15	64 ± 25	20 ± 8
^{58}Cr			480 ± 150	570 ± 150	330 ± 150
^{59}Mn			25 ± 5		
$^{60}\text{Mn}^m$			75 ± 40	49 ± 25	
^{61}Mg			96 ± 40	84 ± 25	
^{62}Mn			944 ± 300	584 ± 100	
^{64}Fe					1.6 ± 0.8

Table 7. N/Z dispersion parameters of the mean cross sections per photon†

Target nucleus	Mass region	A_m	N/Z_p	Z_p	FWHM	ΔZ	Ref.
^{51}V	42–48	45	1.16	20.8	0.143	1.36	Present work
			1.16	20.8	0.142	1.37	[26]
			1.16	20.9	0.168	1.63	[35]
^{55}Mn	42–48	45	1.16	20.8	0.142	1.37	Present work
^{56}Fe	42–48	45	1.16	20.8	0.140	1.35	Present work
			1.16	20.8	0.126	1.38	Present work
			1.16	20.8	0.141	1.36	Present work
^{59}Co	48–54	51	1.16	23.6	0.124	1.36	Present work
			1.16	23.6	0.124	1.36	Present work

† A_m is the median mass of the mass region under consideration. N/Z_p is the neutron/proton ratio for the most probable nuclear charge Z_p of A_m . FWHM is the full width at half-maximum of the CD curves. ΔZ is the spread in Z as calculated from the FWHM for the two abscissas N/Z_p and N/Z_p (see also Refs. [26] and [35]).

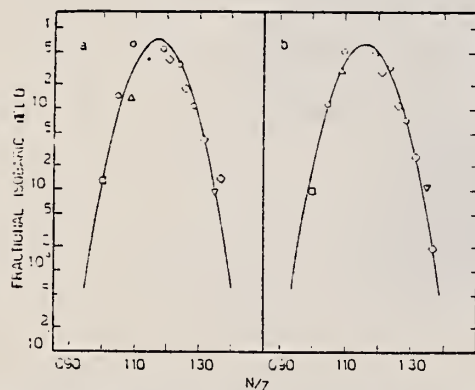


Fig. 1. Fractional isobaric yield vs. the N/Z ratio for $42 \leq A \leq 48$. Mean cross sections per photon in the energy range 0.3–1 GeV. Graph (a): ^{51}V target; (b): ^{55}Mn target. The symbols are: \square , for Cr; \circ , for Sc; Δ , for V; \diamond , for K; ∇ , for Ca isotopes.

METHOD

REF. NO.

78 Ma 10

hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	10-68	C	30-68	ACT		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

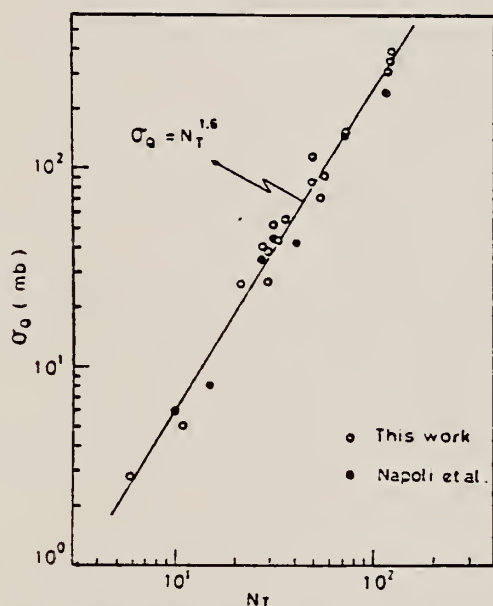


Fig. 2. Yield per equivalent quanta versus target neutron number.

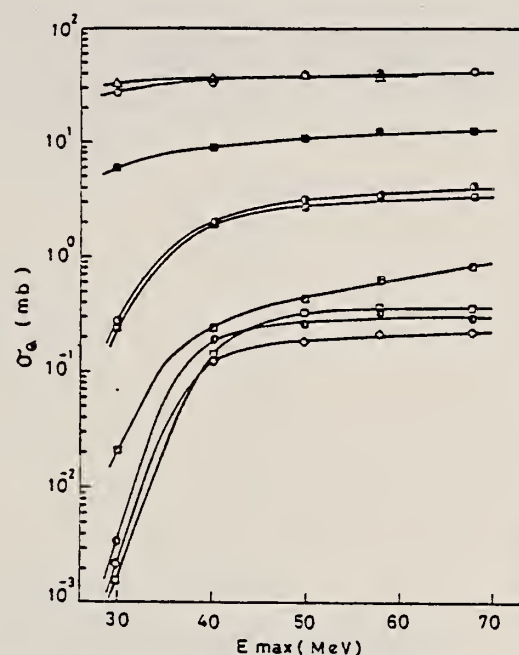


Fig. 5. Activation yield curves for the reactions on Cr, Mn and Fe.

○ $^{52}\text{Cr}(\gamma, n)^{51}\text{Cr}$, ● $^{50}\text{Cr}(\gamma, pn)^{48}\text{V}$, ⊙ $^{50}\text{Cr}(\gamma, 2n)^{48}\text{Cr}$,
△ $^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$, ▴ $^{57}\text{Fe}(\gamma, p)^{56}\text{Mn}$, ▤ $^{54}\text{Fe}(\gamma, pn)^{52}\text{Mn}$,
▥ $^{56}\text{Fe}(\gamma, pn)^{54}\text{Mn}$, □ $^{56}\text{Fe}(\gamma, xn)^{51}\text{Cr}$, ◇ $^{54}\text{Fe}(\gamma, 2n)^{52}\text{Fe}$.

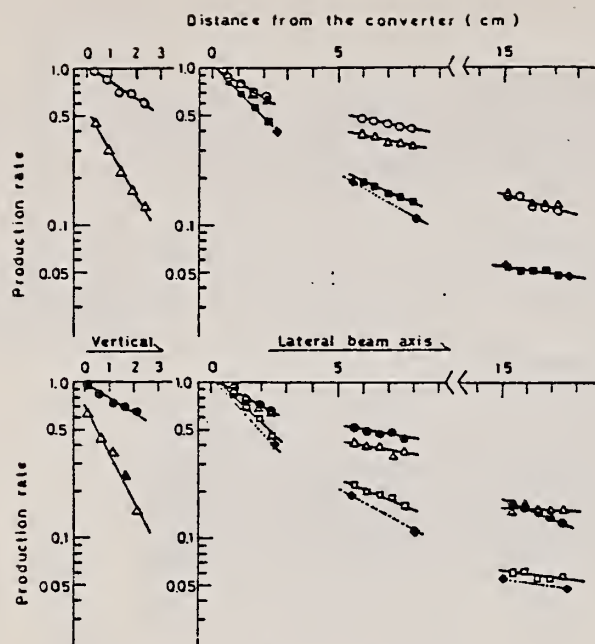


Fig. 13. Production rates of the neutron reactions and the photonuclear reactions as a function of distance from the converter in vertical and lateral directions.

○ $^{55}\text{Mn}(n, \gamma)^{56}\text{Mn}$, ● $^{23}\text{Na}(n, \gamma)^{24}\text{Na}$, △ $^{27}\text{Al}(n, \alpha)^{24}\text{Na}$,
 ■ $^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$, □ $^{23}\text{Na}(\gamma, n)^{22}\text{Na}$, ◆ $^{65}\text{Cu}(\gamma, n)^{64}\text{Cu}$.

REF. J. L. Zyskind, J. M. Davidson, M. T. Esat, M. H. Shapiro
and R. H. Spear
Nucl. Phys. A301, 179 (1978)

ELEM. SYM.	A	Z
Mn	55	25

METHOD

REF. NO.	
78 Zy 1	rs

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G/	ABX	9-13	D	1-4	SCD-D		55

WIGNER CUSP

Abstract: Absolute cross sections for the reactions $^{54}\text{Cr}(p, \gamma)^{55}\text{Mn}$ and $^{54}\text{Cr}(p, n)^{54}\text{Mn}$ are presented for effective bombarding energies E_p from 0.830 to 3.606 MeV. A substantial cusp is observed in the $^{54}\text{Cr}(p, \gamma)^{55}\text{Mn}$ excitation function. The data are compared with the predictions of global Hauser-Feshbach models in order to evaluate their applicability to nucleosynthesis calculations.

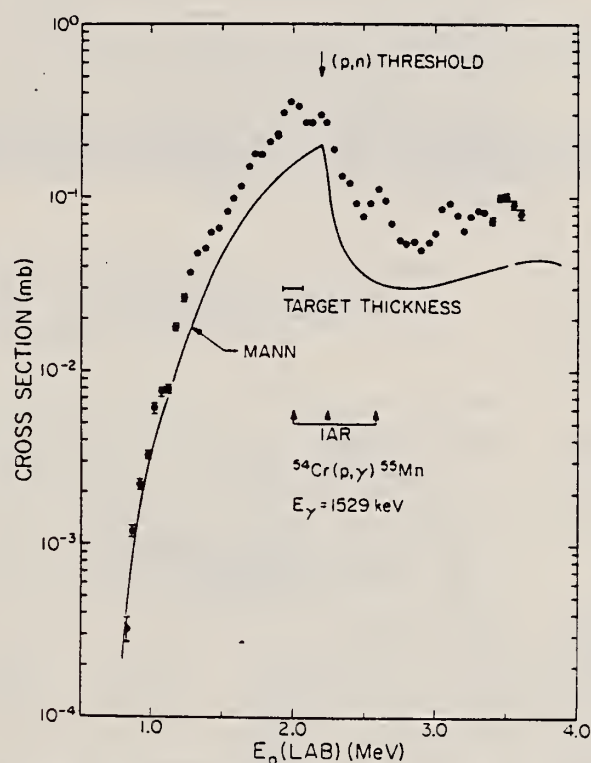


Fig. 1. Excitation function for production of 1529 keV γ -rays in the reaction $^{54}\text{Cr}(p, \gamma)^{55}\text{Mn}$. Error bars shown are statistical only. The curve shows the results of a Hauser-Feshbach calculation performed using Mann's Code ³⁾. The arrows labelled IAR indicate proton energies for isobaric-analogue resonances which have been previously observed ²⁰⁾.

3) F. M. Mann, Hanford Engineering Department Laboratory report HEDL-TME 76-80 (1976)

20) J. D. Moses, H. W. Newson, E. G. Bilpuch and G. E. Mitchell, Nucl. Phys. A175 (1971) 556

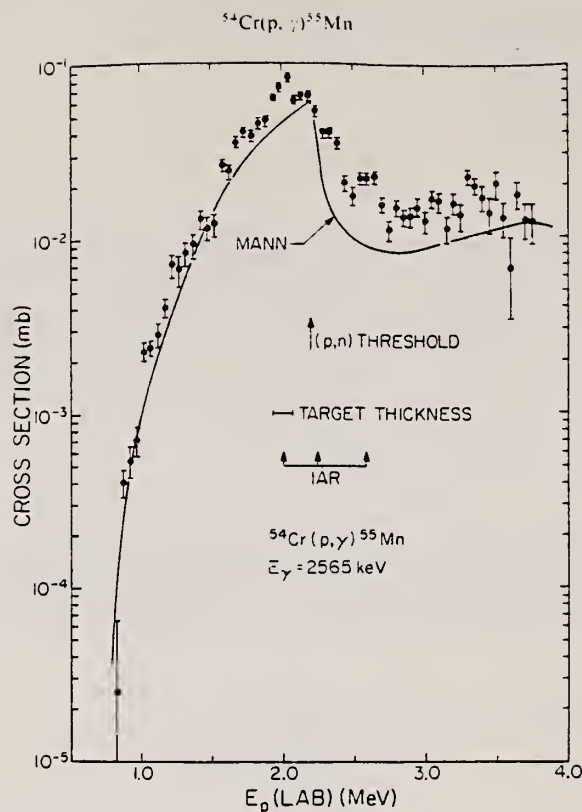


Fig. 2. Excitation function for production of 2565 keV γ -rays in the reaction $^{54}\text{Cr}(p, \gamma)^{55}\text{Mn}$. Error bars shown are statistical only. The curve shows the results of a Hauser-Feshbach calculation performed using Mann's code ³⁾. The arrows labelled IAR indicate proton energies for isobaric-analogue resonances which have been previously observed ²⁰⁾.

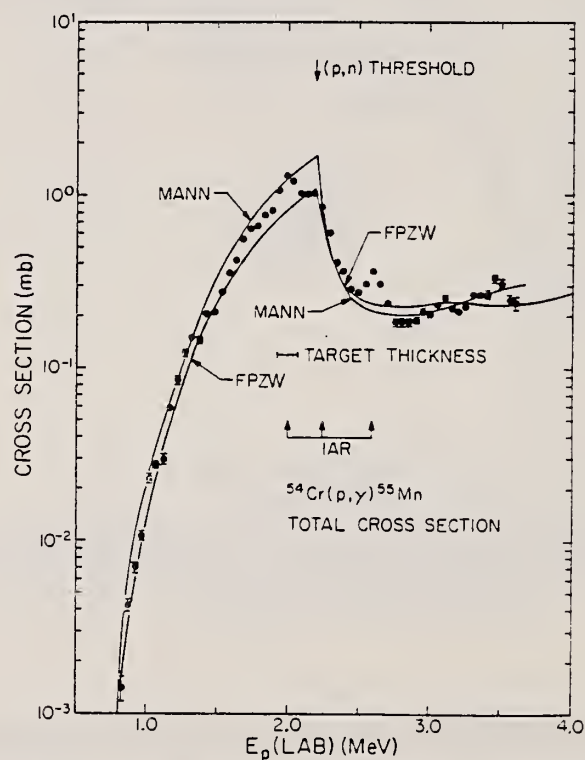


Fig. 3. Excitation function for all primary γ -rays emitted in the reaction $^{54}\text{Cr}(p, \gamma)^{55}\text{Mn}$. Error bars shown are statistical only. The curves show the results of Hauser-Feshbach calculations performed using the codes of Mann ³⁾ and Fowler *et al.* (FPZW) ¹⁸⁾. The arrows labelled IAR indicate proton energies for isobaric-analogue resonances which have been previously observed ²⁰⁾.

ELEM. SYM.	A	Z
Mn	55	25
METHOD		
REF. NO.		hg
79 A1 2		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, 1N	ABX	10-37	D	10-37	BF3-I		4PI
G, 2N	ABX	19-37	D	17-37	BF3-I		4PI
G, 3N	ABX	31-37	D	29-37	BF3-I		4PI

Data fits given use Lorentz Lines,
Kerman & Quang, & Dynamic Collective
Models

Photoneutron cross sections, including $\sigma[(\gamma, n) + (\gamma, pn)]$, $\sigma(\gamma, 2n)$, and $\sigma(\gamma, 3n)$, were measured for ^{55}Mn and ^{59}Co from threshold to 36.5 MeV, with a photon energy resolution which varied from 80 keV at the lowest to 170 keV at the highest energies measured. The source of radiation was the monoenergetic photon beam obtained from the annihilation in flight of fast positrons. The partial photoneutron cross sections were determined by neutron multiplicity counting, and the average neutron energies for $(\gamma, 1n)$ and $(\gamma, 2n)$ events were determined simultaneously with the cross-section data by the ring-ratio technique. The cross sections exhibit considerable but weak structure. Other nuclear information extracted from the data includes parameters of the giant dipole resonance, integrated cross sections and their moments, and nuclear symmetry energies. A comparison is made with previous experimental data for these nuclei as well as with theoretical predictions based upon hydrodynamic, vibrational, and dynamic collective models. None of these models fits the data for these odd-even nuclei satisfactorily; more theoretical work is needed for this nuclear mass region.

NUCLEAR REACTIONS ^{55}Mn , $^{59}\text{Co}(\gamma, n, 2n, 3n)$, $E_\gamma = 10 - 36.5$ MeV; measured 4π neutron yield, multiplicities, average energies for monoenergetic photons; $\sigma(E_\gamma, 1n)$, $\sigma(E_\gamma, 2n)$, $\sigma(E_\gamma, 3n)$, GDR parameters, integrated cross sections and moments, nuclear symmetry energies.

TABLE II. Parameters of two-component Lorentz-curve fits to the GDR. The fitting interval used is 14 to 21 MeV.

Nucleus	$E_m(1)$ (MeV)	$\sigma_m(1)^a$ (mb)	$\Gamma(1)$ (MeV)	$E_m(2)$ (MeV)	$\sigma_m(2)^a$ (mb)	$\Gamma(2)$ (MeV)	χ^2
^{55}Mn	16.82 ± 0.10	51.4 ± 4.1	4.33 ± 0.63	20.09 ± 0.12	45.2 ± 2.6	4.09 ± 1.07	1.14
^{59}Co	16.43 ± 0.08	28.3 ± 5.4	2.73 ± 1.08	18.66 ± 0.25	58.4 ± 4.4	7.38 ± 0.79	1.11

^aUncertainties for σ_m given here are relative. The absolute uncertainties are 7%.

TABLE III. Integrated cross sections. $\sigma_{\text{int}}(\gamma, x) = \int \sigma(\gamma, x) dE_\gamma$, integrated from threshold to $E_{\gamma\text{max}}$.

Nucleus	$E_{\gamma\text{max}}$ (MeV)	$\sigma_{\text{int}}(\gamma, 1n)$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, 2n)$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, 3n)$ (MeV-mb)	$\frac{\sigma_{\text{int}}(\gamma, 2n)}{\sigma_{\text{int}}(\gamma, 1n)}$	$\frac{\sigma_{\text{int}}(\gamma, 3n)}{60NZ/A}$	$\frac{\frac{1}{2}\pi[\sigma_m(1)\Gamma(1) + \sigma_m(2)\Gamma(2)]}{60NZ/A}$
^{55}Mn	36.5	567	163	3	0.222	0.90	0.78
^{59}Co	36.5	653	150	4	0.186	0.92	0.91

TABLE IV. Integrated cross-section moments. $\sigma_{-1} = \int \sigma(\gamma, n_i) E_\gamma^{-1} dE_\gamma$ and $\sigma_{-2} = \int \sigma(\gamma, n_i) E_\gamma^{-2} dE_\gamma$, integrated from threshold to $E_{\gamma\text{max}}$.

Nucleus	σ_{-1} (mb)	$\sigma_{-1} A^{-4/3}$ (mb)	σ_{-2} (mb-MeV ⁻¹)	$\frac{\sigma_{-2}}{0.00225A^{5/3}}$	$\frac{\sigma_{-2}K}{0.05175A^{5/3}}$	$\frac{0.05175A^{5/3}}{\sigma_{-2}}$ (MeV)
^{55}Mn	36.4	0.174	1.93	1.08	0.91 ^a	21.3
^{59}Co	40.1	0.174	2.14	1.06	0.90 ^a	21.7

^aThe values used for the nuclear symmetry energy K are from Table VI.

(over)

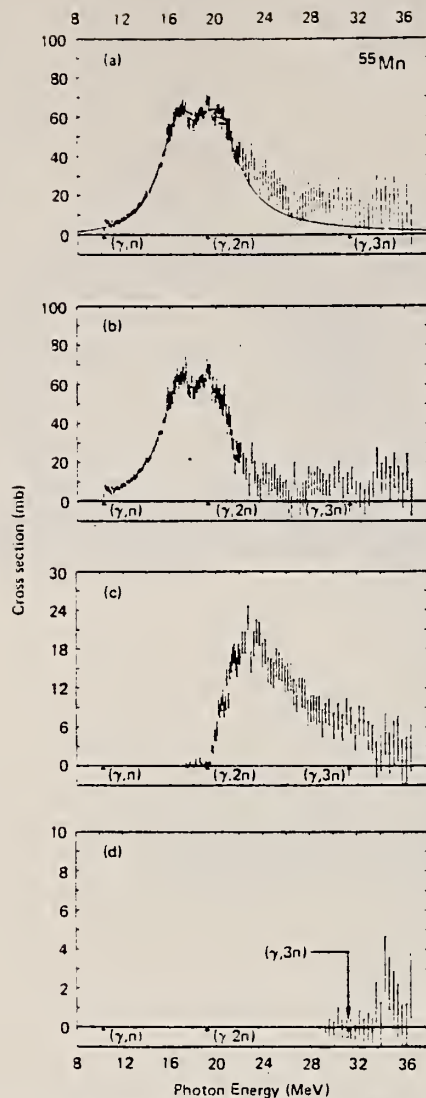


FIG. 2. Photoneutron cross sections for ^{55}Mn : (a) total photoneutron cross section $\sigma(\gamma, n_t) = \sigma(\gamma, 1n) + \sigma(\gamma, 2n) + \sigma(\gamma, 3n)$, together with a two-component Lorentz-curve fit to the data (solid line); (b) single-photon cross section $\sigma(\gamma, 1n) = \sigma[(\gamma, n) + (\gamma, p n)]$; (c) double-photon cross section $\sigma(\gamma, 2n)$; (d) triple-photon cross section $\sigma(\gamma, 3n)$.

Error bars show statistical uncertainties only.

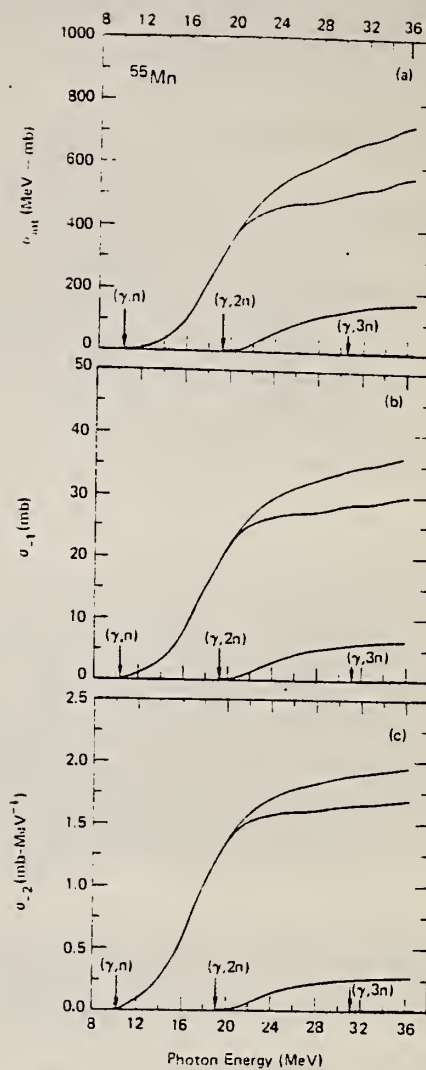


FIG. 4. Running sums of integrated photoneutron cross sections and their moments for ^{55}Mn : (a) $\sigma_{\text{int}} = \int \sigma dE$ for $\sigma(\gamma, n_t)$ (top), $\sigma(\gamma, 1n)$ (next to top), $\sigma(\gamma, 2n)$ (next to bottom), and $\sigma(\gamma, 3n)$ (bottom); (b) $\sigma_{-1} = \int \sigma E dE$; (c) $\sigma_{-2} = \int \sigma E^2 dE$.

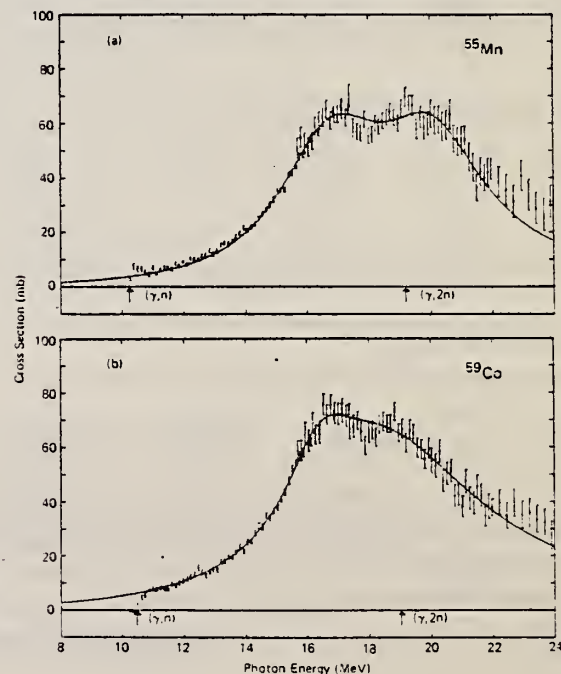


FIG. 6. Total photoneutron cross sections, with two-component Lorentz-curve fits: (a) for ^{55}Mn ; (b) for ^{59}Co . Although the theoretical model is strictly valid only for $\sigma(\gamma, \text{tot})$, the curve shown here was scaled to fit the measured $\sigma(\gamma, n_t)$ data (see Sec. III B in the text and Table III).

MN
A=56

MN
A=56

MN
A=56

Elem. Sym.	A	Z
Mn	56	25
Ref. No.		JOC
61 Ca 1		

Method
Radioactivity

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Cr}^{54}(\text{d}, \gamma)$	3.5-4.5					At $E_d = 4.5 \text{ MeV}$, $\sigma(\text{d}, \gamma) = 295 \pm 45 \mu\text{b}$.

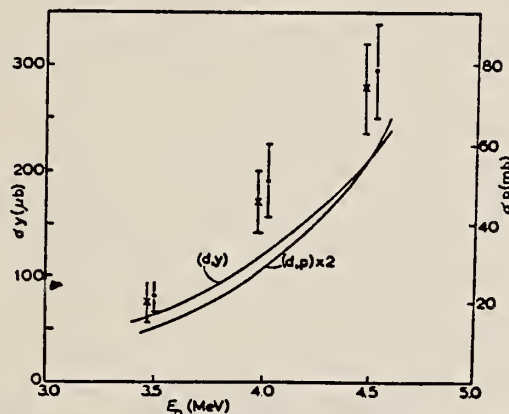


Fig. 2. Cross-sections for the reactions $\text{Cr}^{54}(\text{d}, \gamma)$ - denoted by dots - and $\text{Cr}^{54}(\text{d}, \text{p})$ - denoted by crosses - as a function of deuteron energy. The full curves are given by the statistical theory; the theoretical cross-section for (d, p) has been doubled to show the constancy of the ratio of the cross-sections.

TABLE 1
Results for 4.5 MeV deuterons

Initial nucleus	Reaction	$\sigma_{\text{exp}} (\pm 15 \%)$	$\sigma_{\text{stat theor}}$	σ_{rel} (direct capture)
Ni^{58}	(d, γ)	61 μb	48 μb	61 μb (assuming the measured σ to be totally accounted for by this process)
	(d, n)	85 mb	64 mb	
	$\frac{(\text{d}, \gamma)}{(\text{d}, \text{n})}$	0.7×10^{-3}	0.75×10^{-3}	
	(d, n)			
Zn^{64}	(d, γ)	80 μb	86 μb	192 μb
	$(\text{d}, \text{n}) + (\text{d}, \text{p})$	160 mb	175 mb	
	$\frac{(\text{d}, \gamma)}{(\text{d}, \text{n})}$	0.5×10^{-3}	0.49×10^{-3}	
	$(\text{d}, \text{n}) \times (\text{d}, \text{p})$			
Cr^{54}	(d, γ)	295 μb	215 μb	1280 μb
	(d, p)	75 mb	29 mb	
	$\frac{(\text{d}, \gamma)}{(\text{d}, \text{p})}$	3.9×10^{-3}	7.4×10^{-3}	
	(d, p)			

† There is a misprint in eq. (5) of ref. 1), the right side of which should be divided by π . Eq. (5) of ref. 1) is correct.

Ref 1: Carver & Jones - Nuclear Phys. 11, 400, (1959)

Fe

IRON
Z=26

Iron has the chemical symbol Fe from the Latin "*ferrum*" and has been known since prehistoric times. Writings of most of the earliest civilizations refer to it and there is evidence that it was known in the ancient world over 8000 years ago. However, prior to 2000 B. C., iron was a rare metal, apparently derived from meteorites. From this time onward, iron derived from ore became an increasingly used metal. Its smelting and fabrication were practiced all over the civilized world by processes similar to those used now.

Fe

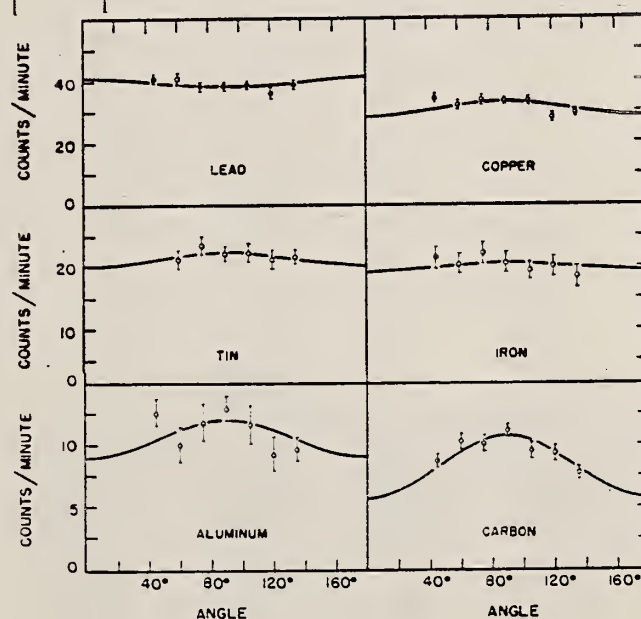
Fe

Method Synchrotron; neutron angular distribution; scintillator; ion chamber

Ref. No.	
55 Di 1	NVB

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
Fe(γ, xn)	70					Isotropy suggests evaporation in heavy nuclei. Curves fitted to $a + b \sin^2 \theta$

Target	Correction factor for self-scattering	Corrected b/a
Lead	1.10	-0.08 ± 0.08
Tin	1.08	0.12 ± 0.17
Copper	1.48	0.23 ± 0.15
Iron	1.35	0.09 ± 0.25
Aluminum	1.17	0.36 ± 0.29
Carbon	1.8	1.6 ± 0.8
Beryllium (1)	2.6	1.2 ± 0.4
Beryllium (2)	1.35	



Elem. Sym.	A	Z
Fe	.	26
Ref. No 60 Re 1		JHH

Method γ 's from F^{19} (p, α) reaction; protons from Van de Graaff; NaI.

Ref. No	
60 Re 1	JHH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(γ, γ)	$E_\gamma \sim 7 \text{ MeV}$					$\langle \sigma \rangle (E_\gamma = 2.05 \text{ MeV}) = 0.40 \pm .06 \text{ mb}$

Ref. M. Kregar, B. Povh
 Nuclear Phys. 43, 170 (1963)
 Erratum in Nuclear Phys. 47, 528 (1963)

Elem. Sym.	A	Z
Fe		26

Method Betatron; α yields; solid state detectors; NBS chamber monitor

Ref. No.	
63 Kr 1	JHH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
Fe(γ, α)	Bremss.					
	21					
	30					

TABLE I
Relative yields

Element	21 MeV		30 MeV	
	Number of alphas	Relative yield at 90°	Number of alphas	Relative yield at 90°
Ni	1209	40	536	13
Cu	1124	13	590	7
Fe	1108	4.5	653	1.7
V	372	1	363	1
Cd	136	0.7		

Method $\text{Li}(p,\gamma)$ source; 480 keV protons; BF_3 counter

Ref. No.	
56 Ha 1	EGF

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Fe}(\gamma, xn)$						<p>Average Li cross section is 38 mb; cross section with detector response weighted for low energy neutrons, 33 mb.</p> <p>Assumed ratio $17.6/14.8 = 1.7$.</p> <p>Calculated cross section at 14.8 and 17.6 MeV assuming cross section curves measured at Pennsylvania and Saskatchewan (refer Table I).</p> <p>¹McDaniel, Walker, and Stearns, Phys. Rev. 80, 807 (1950) ²J. S. Levinger and H. A. Bethe, Phys. Rev. 78, 115 (1950) ³Montalbetti, Katz, and Goldemberg, Phys. Rev. 91, 659 (1953). ⁴R. Nathans and J. Halpern, Phys. Rev. 93, 437 (1954). ⁵J. Goldemberg and L. Katz, Can. J. Phys. 32, 49 (1954).</p>

TABLE I. Cross sections for photoneutron emission induced by the lithium gamma rays. The results are compared with previous data.

Element	Present cross-section data		Data of McDaniel et al. ^a	Betatron data						
				Pennsylvania		Saskatchewan				
	Counter Group A	Counter Group B		$\sigma_{14.8}^b$	$\sigma_{17.6}^b$	$\sigma_{14.8}^b$	$\sigma_{17.6}^b$	$\sigma_{14.8}^b$	$\sigma_{17.6}^b$	
				$\sigma_{14.8}^b$	$\sigma_{17.6}^b$	$\sigma_{14.8}^b$	$\sigma_{17.6}^b$	$\sigma_{14.8}^b$	$\sigma_{17.6}^b$	
⁵⁴ Fe	38 mb	33 mb	37 mb			60 ^f mb	0.5	23 mb	47 mb	
⁵⁸ Co	49	49	47	60 ^a mb	0.5		95 ^f	0.5	30	60
⁵⁸ Ni	28	25	23				40 ^a	0.7	22	32
⁶³ Cu	64	61	55±12				95 ^f	0.6	45	75
⁶⁶ Zn	48	45	48				90 ^f	0.7	38	54
⁶⁷ Ag	175	170	135				250 ^f	1.0	175	175
¹¹⁸ Sn	200	190	180							
⁷¹ Ta	355	360	260	350 ^d	1.3		420 ^e	2.3	420 ^f	320 ^f
⁷¹ W	365	355	325						550 ^f	240 ^f
⁷⁹ Au	330	295		315 ^e	1.7		480 ^f	1.9	460	255
⁸⁰ Hg	365	340	290							
⁸² Pb	310	295	250	320 ^e	1.6		440 ^f	2.5	400 ^f	250 ^f
⁸³ Bi	305	280	250	270 ^d	2.6		550 ^f	2.4	500 ^f	200 ^f
									490	195

- ^a See reference 3.
^b Average of 14.8- and 17.6-Mev cross sections weighted with relative intensities of the lithium gamma-ray lines.
^c See reference 24.
^d R. Nathans, Ph.D. thesis, University of Pennsylvania, 1954 (unpublished).
^e J. Halpern (private communication).
^f See reference 32.
^g See reference 32.
^h Separate cross sections at 14.8 and 17.6 Mev as obtained from Group A data and 14.8/17.6 betatron cross-section ratios.
ⁱ Obtained using 14.8/17.6 cross-section ratio from Pennsylvania betatron data.
^j Obtained using 14.8/17.6 cross-section ratio from Saskatchewan betatron data.

Ref. M.E. Toms, J. McElhinney
Phys. Rev. 111, 561 (1958)

Elem. Sym.	A	Z
Fe		26

Method Betatron; alpha yield; nuclear emulsion

Ref. No.	
58 To 2	NVB

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
Fe(γ, α)	Bremss. 22					Yield = 1.9×10^4 alpha/mole/roentgen

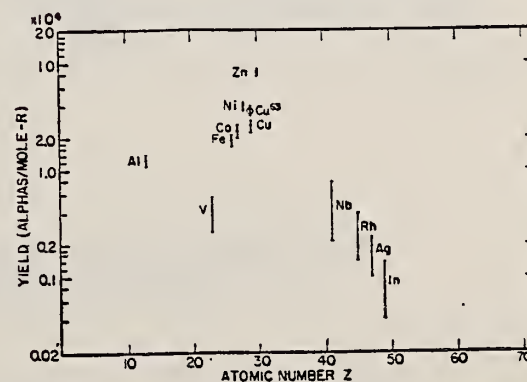


FIG. 8. Photo-alpha yields plotted against atomic numbers for the exposures of the survey.

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
59 Ko 1		EH

METHOD

30 MeV synchrotron; NaI(Tl) scintillator spectrometer; photon

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
$\text{Fe}(\sigma_t)$		10 - 27	C	10-27	NAI		

TABLE 2

Experimentally determined giant resonance data; peak energy, E_{max} , width at half height, ΔE , and integrated cross section, $\int_{10 \text{ MeV}}^{27 \text{ MeV}} \sigma dE$, and values of $\int_0^{\infty} \sigma dE$ predicted by the dipole sum rule.

Absorber	E_{max} (MeV)	ΔE (MeV)	$\int_{10 \text{ MeV}}^{27 \text{ MeV}} \sigma dE$	$\int_0^{\infty} \sigma dE$
Carbon	23	4.6	0.12	0.18
Aluminium	21.5	7.8	0.24	0.40
Sulphur	21	6.6	0.30	0.48
Iron	19.5	9.4	0.76	0.84

- ¹⁷) J. Halpern and A. K. Mann, Phys. Rev. 83 (1951) 370.
¹⁸) R. Montalbetti, L. Katz and J. Goldemberg, Phys. Rev. 91 (1953) 659.
¹⁹) L. W. Jones and K. M. Terwilliger, Phys. Rev. 91 (1953) 699.
²⁰) W. C. Barber, W. D. George and D. D. Reagan, Phys. Rev. 98 (1955) 73.
²¹) F. Ferrero, R. Malvano, S. Menardi and O. Terracini, Nuclear Physics 9 (1958) 32.
²²) L. Katz and A. S. Penfold, Phys. Rev. 81 (1951) 815.
²³) S. A. E. Johansson, Phys. Rev. 97 (1955) 1186.

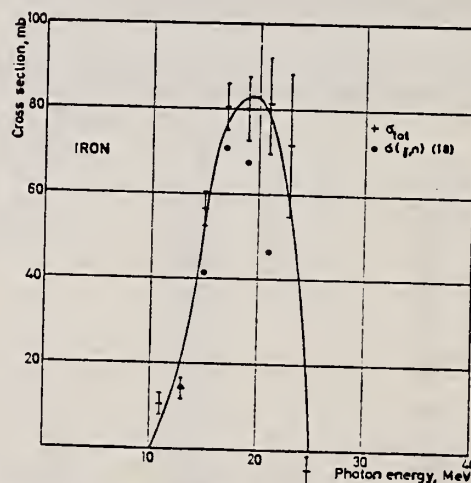


Fig. 4. Experimentally determined photonuclear absorption cross sections (crosses). The open circles show the sum of the (γ, n) , and (γ, p) cross sections and the filled squares the $(\gamma, np) + (\gamma, d)$ cross section where available^{17, 18, 20-22}). The filled circles give the total photonuclear absorption cross section as measured by Ziegler²³).

²³) B. Ziegler, Z. Physik 152 (1958) 566.

ELEM. SYM.	A	Z
Fe		26

METHOD				REF. NO.	
Betatron; fast neutron yield; angular distribution; Si threshold detector; ion chamber.				61 Ba 2	NVB
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,XN	ABY	THR- 22	C	22	DST

In Table IV: $\bar{\sigma}$ = average cross section of detector weighted with neutron spectrum;

ϕ = neutrons/100 roentgen/mole

$$W(\theta) = a_0 \sum_{n=1}^{\infty} (1 + a_n P_n(\cos\theta))$$

TABLE IV

I Element	II a_0	III a_1	IV a_2	V $(\bar{\sigma}\phi) \times 10^{10}$	VI $\phi_{\text{total}} (22 \text{ Mcv}) \times 10^9$	VII $\phi_{\text{fast}}/\phi_{\text{total}}$
Vanadium	215 (1±0.06)	0.01±0.08	-0.00±0.10	6.05	0.21	0.12
Chromium	161 (1±0.03)	0.04±0.04	-0.05±0.05	4.05	0.17	0.10
Manganese	308 (1±0.02)	0.07±0.03	-0.09±0.04	7.61	0.25	0.12
Iron	200 (1±0.03)	0.05±0.04	-0.17±0.05	4.94	0.18	0.11
Cobalt	390 (1±0.02)	0.08±0.03	-0.22±0.04	9.63	0.26	0.15
Nickel	145 (1±0.05)	0.07±0.07	-0.23±0.09	3.58	0.12	0.12
Copper	347 (1±0.02)	0.05±0.03	-0.29±0.04	8.57	0.30	0.12
Arsenic	482 (1±0.03)	0.11±0.04	-0.24±0.05	11.91	0.33	0.15
Rubidium	638 (1±0.05)	0.13±0.06	-0.14±0.08	15.76		
Strontium	409 (1±0.05)	0.10±0.06	-0.17±0.08	10.10		
Yttrium	290 (1±0.10)	0.08±0.12	-0.12±0.15	7.16		
Silver	590 (1±0.01)	0.10±0.06	-0.22±0.08	14.57	0.87	0.07
Cadmium	905 (1±0.02)	0.02±0.02	-0.26±0.03	22.35		
Iodine	1133 (1±0.03)	0.04±0.04	-0.29±0.05	27.99	1.42	0.08
Barium	1018 (1±0.01)	0.10±0.06	-0.38±0.08	25.89		
Lanthanum	1595 (1±0.02)	0.02±0.03	-0.42±0.04	39.40	1.04	0.15
Cerium	1316 (1±0.05)	0.05±0.06	-0.39±0.08	32.50		
Dysprosium	1652 (1±0.08)	0.04±0.10	-0.34±0.13	40.80		
Tantalum	1558 (1±0.02)	0.04±0.03	-0.22±0.04	38.48	2.50	0.06
Tungsten	1365 (1±0.02)	-0.07±0.03	-0.24±0.04	33.71		
Mercury	1345 (1±0.02)	0.04±0.03	-0.31±0.04	33.22		
Lead	2274 (1±0.01)	0.02±0.02	-0.42±0.03	56.17	2.72	0.08
Bismuth	2162 (1±0.02)	0.05±0.03	-0.45±0.04	53.40	3.36	0.06
Thorium	3031 (1±0.01)	0.06±0.05	-0.32±0.07	74.87		
Uranium	4630 (1±0.02)	0.05±0.03	-0.17±0.04	114.36		

* $(\bar{\sigma}\phi) = 2.47 \times 10^7$ so millibarn-neutron. Errors are standard errors due to counting statistics only.

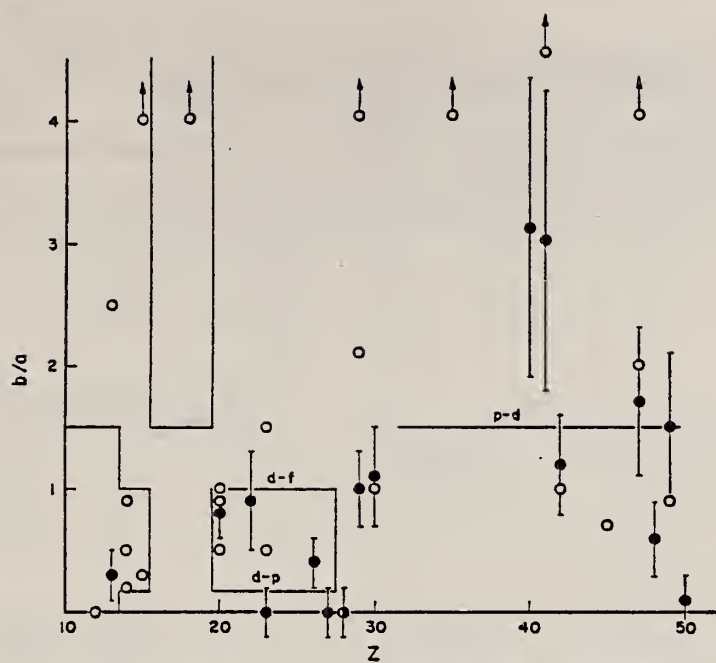


FIG. 4. The values of the fast photoproton anisotropy coefficient b/a found by the present authors (●) and other workers (○) in the region of the periodic table $10 < Z < 50$. Arrows indicate off-scale points. The references to the results of other workers are given in Table II. The demarcations are explained in the text.

Method 25 MeV betatron; photon scattering; NaI spectrometer; NBS chamber

Ref. No.	NVB
63 Su 1	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
Fe(γ, γ)	Bremss. 4-14					<p>Detector at 120°</p> <p>$\sigma_{\max} = 1.3$ mb</p> <p>[Corrects results of J. Phys. Soc. Japan <u>16</u>, 1657 (1961)]</p>

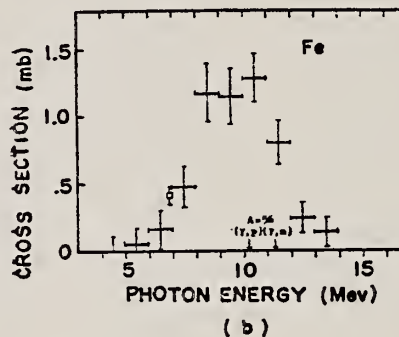


Fig. 2. The elastic scattering cross sections for Mg, Fe, Zn, As, Cd, Sb and Bi. The indicated spread in energy is the width of the sum-up channels, and the vertical lines are the statistical errors including background counts. The arrows represent the positions of the threshold energies of (γ, p) or (γ, n) reaction taken from Ref. 16. The open squares at 7 Mev are Reibel and Mann's data⁹. In Fig. 2(c), the cross section values, which are analyzed by displacing the sum-up channels by five channels to lower energy side than the positions generally used, are indicated by the closed triangles.

- 9) K. Reibel and A. K. Mann: Phys. Rev. 118 (1960) 701.
 10) J. S. Pruitt and S. R. Domen: NBS Monograph 48 (1962).
 11) E. G. Fuller and E. Hayward: J. Research
 15) J. A. Stratton: *Electromagnetic Theory* (McGraw-Hill Book Co., New York, 1941).
 16) *Nuclear Data Sheets*, National Academy of Sciences (N. R. C.).

METHOD

Van de Graaff; resonance fluorescence

REF. NO.

64 Bo 1

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G.G	LFT	1-3	C	1 - 3	NAI-D		100
		(0.5 - 3.0)		(0.5 - 3.0)			

ABI

TABLE 1
 Cases of observed resonance fluorescence

Nucleus multipol.	State (MeV)	Spin	Γ_0/Γ	$T(gw\Gamma_0^2/\Gamma^2)^{-1}$ (sec).	Mean lifetime T BCW (sec)	Mean lifetime T other (sec)	Ref.	Γ_0/Γ_w BCW
Fe^{56}	0.00	0^+						
$E2^+$	0.85	2^+	1	$2.5 \pm 1.2 \times 10^{-12}$	2.4×10^{-12}	$8.5 \pm 2.9 \times 10^{-12}$	"	16

REF.

REF. NO.

Synchrotron; $C^{12}(\gamma, n)$ monitor

64 Co 2

JOC

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XN	ABY	THR - 80	C	80	BF3-I		4 PI

Table 1

Element	Yield (36) eV cm ² mol MeV	60 NZ/A (mb MeV)	30 Σ 0	80 Σ 0	30 80 Σ / Σ 0 0	E_m (MeV)	σ_m (mb)
²⁴ Cr	83 x 10 ⁻⁵	777	1.21	2.1	0.58	18.5	97
²⁵ Mn	108 x 10 ⁻⁵	818	1.52	2.33	0.65	18.5	114
²⁶ Fe	68 x 10 ⁻⁵	832	0.88	1.46	0.60	17.5	75
²⁷ Co	89 x 10 ⁻⁵	878	1.08	1.82	0.59	17.5	92
²⁸ Ni	44 x 10 ⁻⁵	879	0.55	1.07	0.51	18.5	56
²⁹ Cu	95 x 10 ⁻⁵	947	1.06	1.99	0.53	17.5	98
³⁰ Zn	88 x 10 ⁻⁵	975	0.94	1.68	0.56	17.5	86
³¹ Ga	130 x 10 ⁻⁵	1034	1.29	2.18	0.59	17.5	151
³² Ge	139 x 10 ⁻⁵	1064	1.35	2.29	0.59	17.5	158
³³ As	137 x 10 ⁻⁵	1109	1.22	2.18	0.56	17.5	127

$$\Sigma = \frac{\int_0^{30} \sigma(\gamma, xn) dE}{60 \text{ NZ/A}}$$

Table 2

Element	maximum yield (x 10 ⁻⁵)	$\sigma_{-1}(\text{Tn})$	$\sigma_{-1}(\text{Tn}) \times \left[\frac{3}{4\pi^2} \frac{\pi c}{2} \left(\frac{A-1}{NZ} \right) A^{-\frac{2}{3}} \right]$
⁶ C	4.0	3.54	2.18
⁸ O	5.2	4.95	1.92
¹¹ Na	13.6	11.60	2.49
¹² Mg	10.0	8.81	1.73
¹³ Al	15.9	13.92	2.30
¹⁴ Si	11.6	9.96	1.55
¹⁵ P	19.8	17.56	2.32
¹⁶ S	9.5	8.55	1.07
¹⁹ K	19.6	17.90	1.61
²⁰ Ca	12.1	11.68	1.02
²⁴ Cr	86	61.6	3.56
²⁵ Mn	115	76.1	3.96
²⁶ Fe	71	50.5	2.55
²⁷ Co	94	63.5	2.94
²⁸ Ni	46	34.2	1.59
²⁹ Cu	102	72.3	2.98
³⁰ Zn	93	65.7	2.68
³¹ Ga	140	93.6	3.31
³² Ge	150	101.5	3.36
³³ As	151	99.8	3.12

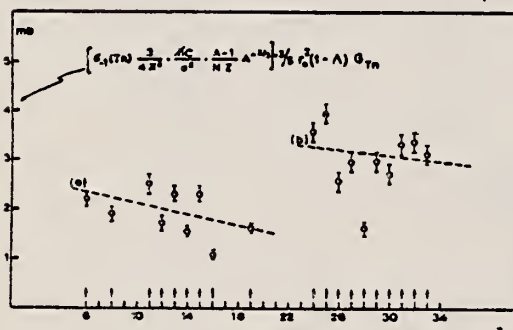


Fig. 2. Bremsstrahlung weighted cross sections, $\sigma_{-1}(\text{Tn})$, conveniently normalized, versus Z.

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
65 Ma 2		NVB

METHOD					REF. NO.	
Cyclotron; μ^- capture					65 Ma 2	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
MU-, XN	NØX	10 - 20	D	0	SCI-I	4PI
		[DO NOT PUT IN DATA INDEX]				

Tries to fit data with Fermi gas and Gaussian momentum distributions.

NEUT MULTIPLICITY

TABLE IV. Corrected experimental results.

Target	Average multiplicity, $\langle n \rangle$	Multiplicity distribution (adjusted to 0.543 efficiency)							
		F_0	F_1	F_2	F_3	F_4	F_5	F_6	F_7
Al	1.262 ± 0.059	0.449 ± 0.027	0.464 ± 0.028	0.052 ± 0.013	0.036 ± 0.007	-0.0023 ± 0.004	-0.001 ± 0.004	0.003 ± 0.004	
Si	0.864 ± 0.072	0.611 ± 0.042	0.338 ± 0.042	0.045 ± 0.018	-0.002 ± 0.008	0.003 ± 0.003	0.002 ± 0.003	0.005 ± 0.006	
Ca	0.746 ± 0.032	0.633 ± 0.021	0.335 ± 0.022	0.025 ± 0.009	0.004 ± 0.006	0.003 ± 0.003			
Fe	1.125 ± 0.041	0.495 ± 0.018	0.416 ± 0.019	0.074 ± 0.011	0.014 ± 0.003	-0.0001 ± 0.003	0.002 ± 0.003		
Ag	1.618 ± 0.060	0.360 ± 0.021	0.456 ± 0.023	0.144 ± 0.017	0.021 ± 0.009	0.007 ± 0.003	0.002 ± 0.004	0.001 ± 0.003	
I	1.436 ± 0.056	0.396 ± 0.021	0.474 ± 0.023	0.087 ± 0.018	0.038 ± 0.009	0.007 ± 0.003	0.0003 ± 0.004		
Au	1.662 ± 0.044	0.370 ± 0.015	0.425 ± 0.016	0.156 ± 0.012	0.032 ± 0.008	0.014 ± 0.004	0.003 ± 0.003	0.0003 ± 0.003	
Pb	1.709 ± 0.066	0.324 ± 0.022	0.483 ± 0.025	0.137 ± 0.018	0.045 ± 0.010	0.011 ± 0.006			
Ag*	1.60 ± 0.18	0.389 ± 0.100	0.453 ± 0.073	0.120 ± 0.033	0.030 ± 0.013	0.001 ± 0.003	0.009 ± 0.006	0.006 ± 0.007	0.010 ± 0.007
Pb*	1.64 ± 0.16	0.348 ± 0.100	0.479 ± 0.057	0.137 ± 0.027	0.018 ± 0.012	0.010 ± 0.005	0.005 ± 0.004	0.003 ± 0.002	0.002 ± 0.002

* Results of Kaplan, Moyer, and Pyle (Ref. 1).

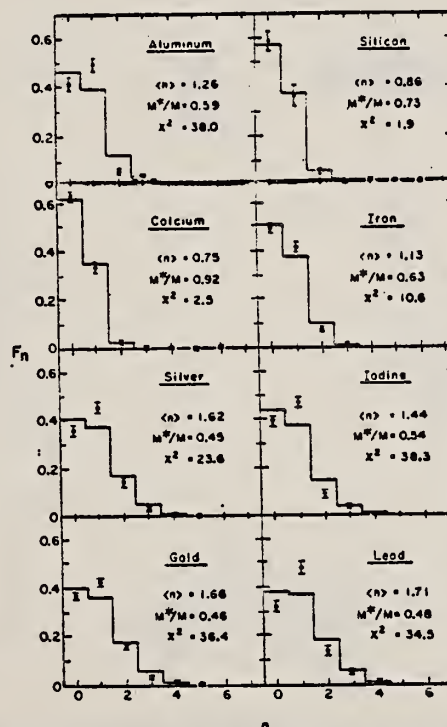


Fig. 11. Comparison of the observed neutron multiplicities with histograms calculated by using the Gaussian momentum distribution, $\alpha^2/2M = 20$ MeV.

ELEM. SYM.	A	Z
Fe		26
REF. NO.	66 Be 1	
	EGF	

METHOD

Van de Graaff

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
N,G	SPC	15	D	7	NAI-D	8-18	

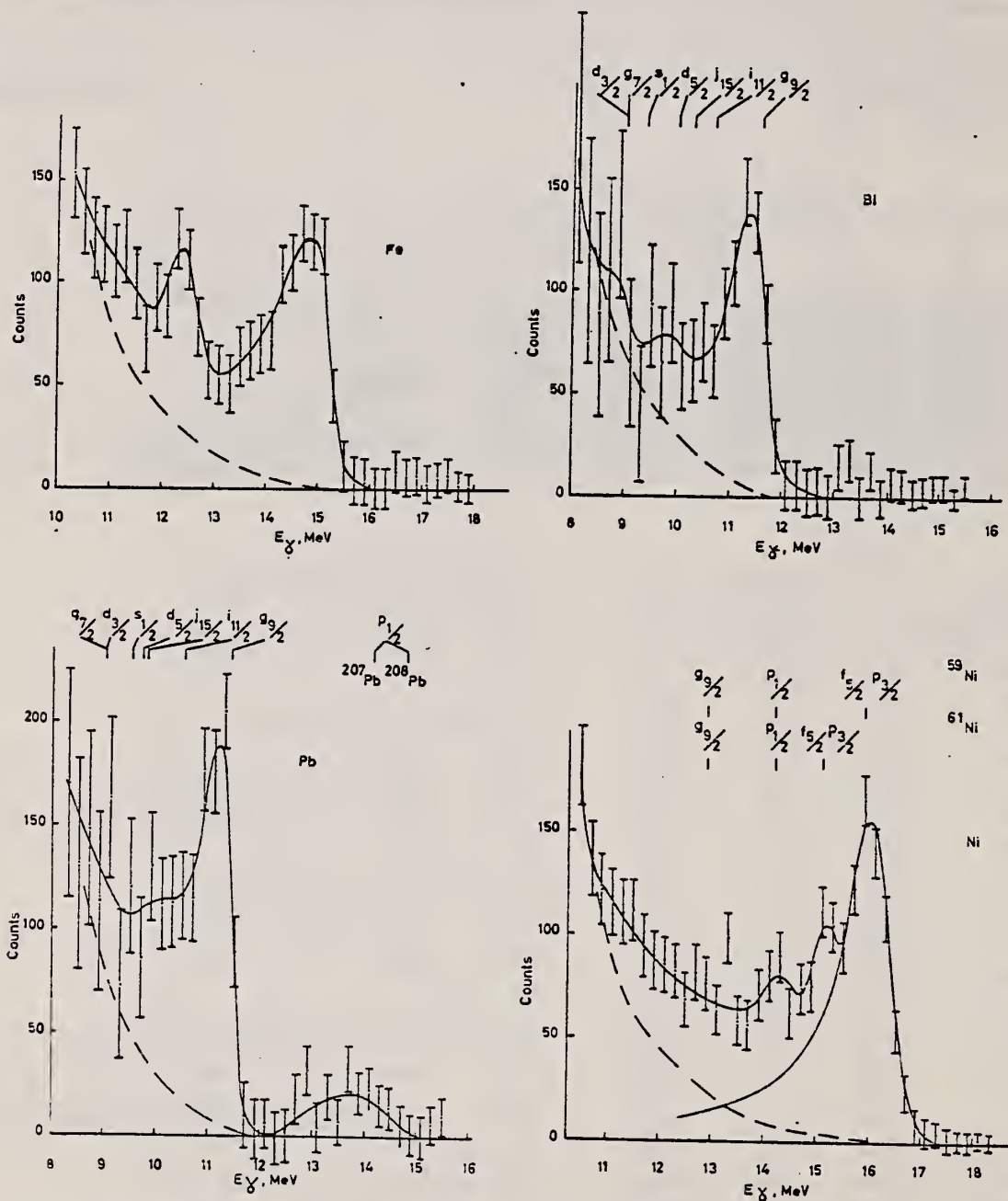


Fig. 1. Gamma-ray spectra emitted in the capture of 7.4 MeV neutrons. The dashed line is the spectrum calculated for the decay of a compound nucleus. The dot-dashed line is the response function of the gamma-ray spectrometer for 16.0 MeV γ rays. Single-particle states as determined from (d,p) reactions are shown.

REF.

W. B. Walters and J. P. Hummel
Phys. Rev. 150, 867 (1966)

ELEM. SYM.

A

Z

Fe

26

METHOD

REF. NO.

Betatron

66 Wa 1

JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,5PXN	RLY	THR-250	C	100-250	ACT-I		4PI
G,PXN	RLY	THR-250	C	100-250	ACT-I		4PI

Measured isomeric yield ratios.

TABLE II. Summary of the results for the photoproduction of the Sc^{44} isomers (spins 2 and 6).

Target isotope and spin	Bremsstrahlung energy (MeV)	Fraction of yield to high-spin isomer
Sc^{44} ($I = \frac{1}{2}$)	50	0.21 ± 0.04
	75	0.21 ± 0.03
	175	0.20 ± 0.02
	223	0.18 ± 0.01
	264	0.17 ± 0.02
	300	0.21 ± 0.02
$\text{Fe}^{54,56}$ ($I = 0$) ^a	250	0.38 ± 0.02
Mn^{55} ($I = \frac{1}{2}$)	225	0.42 ± 0.04
	300	0.39 ± 0.02

^a It is assumed that most of the yield is due to reactions involving the two lightest isotopes present in natural iron (Fe^{54} and Fe^{56}).

TABLE III. Summary of the results for the photoproduction of the Mn^{55} isomers (spins 2 and 6).

Target isotope and spin	Bremsstrahlung energy (MeV)	Fraction of yield to high-spin isomer
$\text{Fe}^{54,56}$ ($I = 0$) ^a	100	0.39 ± 0.03
	150	0.36 ± 0.02
	200	0.35 ± 0.02
	250	0.37 ± 0.02
Mn^{55} ($I = \frac{1}{2}$)	100	0.44 ± 0.04
	150	0.48 ± 0.02
	225	0.47 ± 0.02
	300	0.47 ± 0.02
Co^{59} ($I = \frac{1}{2}$)	150	0.62 ± 0.02

^a It is assumed that most of the yield is due to reactions involving the two lightest isotopes present in natural iron (Fe^{54} and Fe^{56}).

REF. S. Costa, F. Ferrero, C. Manfredotti, L. Pasqualini, C. Piragino,
H. Arenhovel
Nuovo Cimento, 51B, 199 (1967)

ELEM. SYM.	A	Z
Fe		26
REF. NO.		EGF
67 Co 2		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	THR-24	C	11-24	BF3-I		4PI

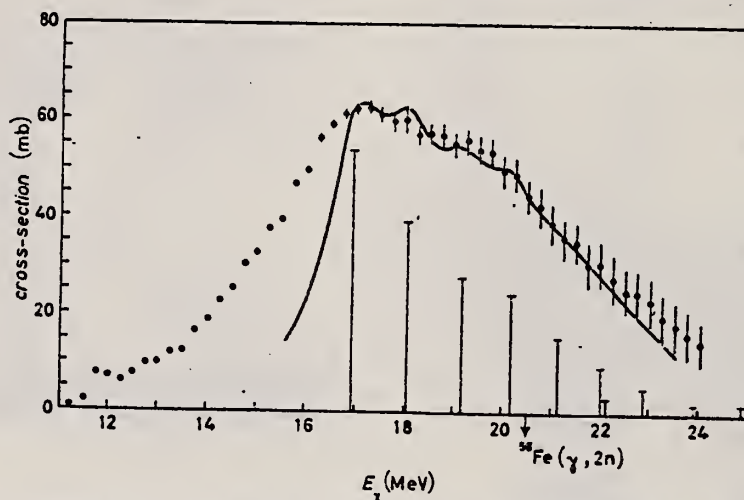


Fig. 2. - Corrected $(\gamma, 2n)$ cross-section for Fe. The dipole strengths, calculated for ^{56}Fe , are indicated by the vertical bars.

C. B. Fulmer, I. R. Williams, T. H. Handley, G. F. Dell, and
L. N. Blumberg
Phys. Rev. Letters 19, 522 (1967)

ELEM. SYM.	A	Z
Fe		26
REF. NO.	67 Fu 1	
	egf	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,F	ABY	THR-999	D	999	ACT-I		4PI

999=3 GEV

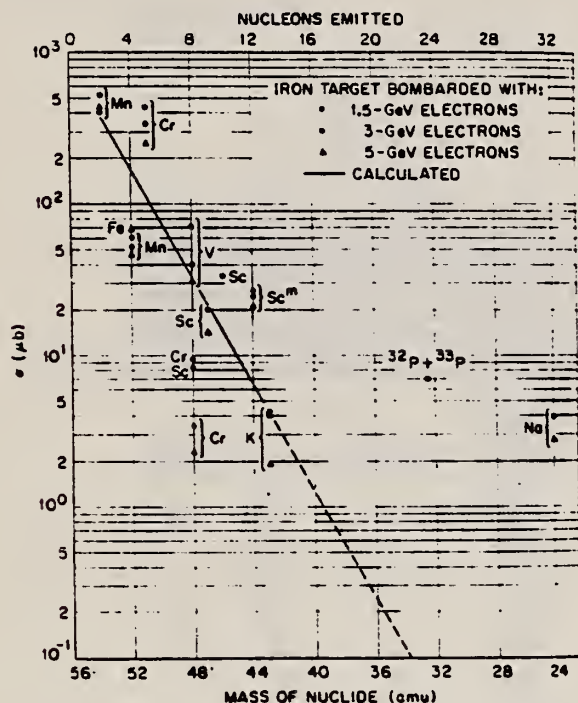


FIG. 1. Yields of radionuclides identified in iron samples that were exposed to a beam of 3-GeV electrons. The values of σ are based on the integrated electron beam intensity.

REF. N. N. Kaushal, E. J. Winhold, P. F. Yergin, H. A. Medicus and
R. H. Augustson
Phys. Rev. 175, 1330 (1968)

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
68 Ka 1		HMG

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	50-85	C	55,85	TOF-D	10-85	67
							(67.5)

NEUT ENGY SPEC

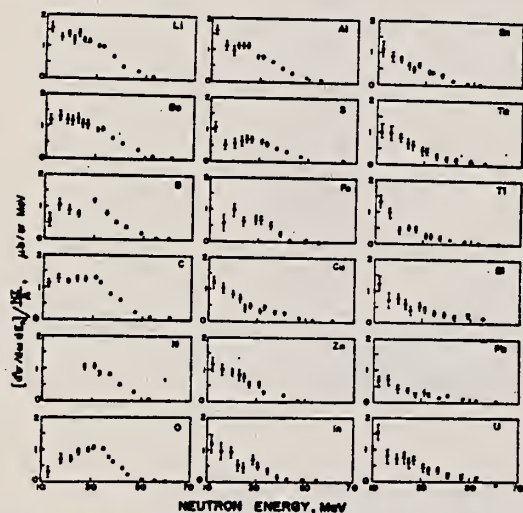


FIG. 6. Observed neutron spectra due to 55-85-MeV difference photon spectra. The effective cross sections have been divided by NZ/A .

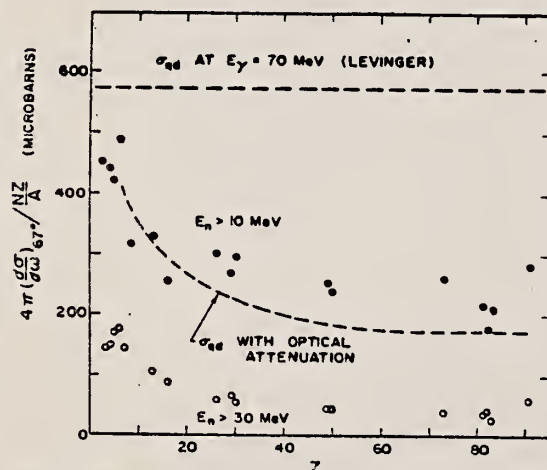


FIG. 7. Effective cross sections for production of fast neutrons with energies greater than 10 MeV (solid circles) and 30 MeV (open circles) by the 55-85-MeV photon difference spectrum. The dashed curves are modified quasideuteron model predictions as discussed in the text.

TABLE I. Comparison of present cross-section values in mb for production of high-energy photoneutrons by 55-85-MeV photons with measured cross sections $\sigma(\gamma, Tn)$, also in mb, for total photoneutron production. The present cross-section values are uncertain by 8 to 10% because of counting statistics and normalization errors; in addition all values depend on an absolute normalization in terms of the deuteron photodisintegration cross section, which is known to about 10% at these energies.

Target	$4\pi(d\sigma/d\Omega)_0^a$ ($E_n > 10$ MeV)	$\sigma(\gamma, Tn)$		Other results
	[Present experiment]	Jones and Terwilliger ^a	Costa <i>et al.</i> ^b	
Li	0.75		1.0	
Be	1.0	2.7	2.3	2.3 ^c
B	1.0		1.4	
C	1.5	1.3	1.4	2.4 ^d
O	1.3		1.6	
Al	2.8	5.5	4.6	8 ^d
S	2.1		4.4	6.5 ^d
Fe	4.2	16	12	
Cu	4.3	20	19	
Zn	4.4		15	
In	7.4			
Sn	7.0			
Ta	10.7	95		
Tl	10.7			
Pb	8.3	100		
Bi	13			
U	16	65		

^a Average cross sections between 55 and 85 MeV, as read from Figs. 4 and 5 of Ref. 4.

^b $\int_{55}^{85} \sigma_{\text{ph}} E - \int_{55}^{85} \sigma_{\text{ph}} E / 50$, as taken from Fig. 4 of Ref. 5 and Table I of Ref. 6.

^c S. Costa, L. Pasqualini, G. Piragino, and L. Roasio. Nuovo Cimento 42, 306 (1966).

^d G. Bishop, S. Costa, S. Ferroni, R. Malvano, and G. Ricco. Nuovo Cimento 42, 148 (1966).

REF.

B. S. Dolbilkin, A. I. Isakov, V. I. Korin, L. E. Lazareva,
N. V. Lin'kova, and B. A. Tulupov
Yad. Fiz. 9, 675 (1969)
Sov. J. Nucl. Phys. 9, 391 (1969)

ELEM. SYM.

Fe

26

METHOD

REF. NO.

69 Do 2

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, MU-T	ABX	10-27	C	THR-260	MGP-D		4PI
		(26.5)					

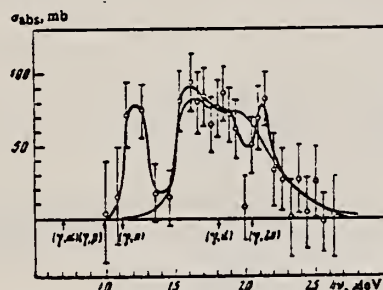


FIG. 1. γ -ray absorption cross section for Fe^{56} . The thin line shows the theoretical calculation.

Integrated cross section for photodisintegration of Fe^{56}

Experiment	E , MeV	E , MeV	σ , mb-MeV
Present work	12.2	~2	~160
	18.1	~7	575
			+120 -80
(γ , Tn), [$^{\circ}$]	18	~7	~450
(γ , Tn), [$^{\circ}$]	18	~7	470
(γ , tot), [$^{\circ}$]	18	9.4	780

REF.

C. B. Fulmer, I. R. Williams, K. S. Toth, G. F. Dell
Phys. Rev. 188, 1752 (1969)

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
69 Fu 2		hmg

METHOD					
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,SPL	RLY	THR-999	D	999	DST
		(THR-3 GEV)		(3 GEV)	

Relative thick target yield as a function of target thickness.

999 = 3 GEV

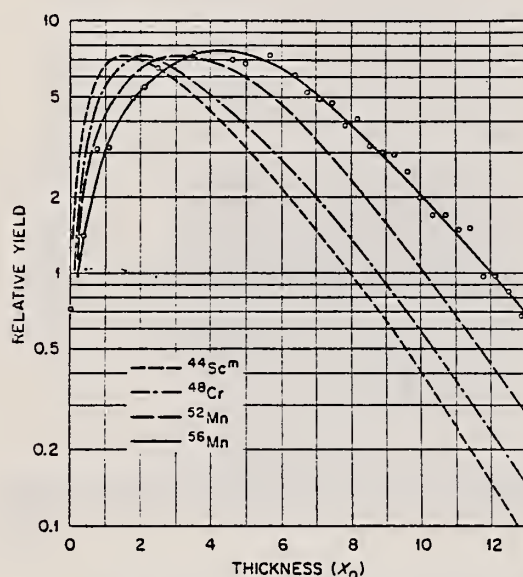


FIG. 1. Relative yields for some nuclides produced in a thick iron target bombarded with 3.0-GeV electrons. The data points shown for ^{52}Mn are typical of the data. The curves are normalized to the same ordinate value at the peaks.

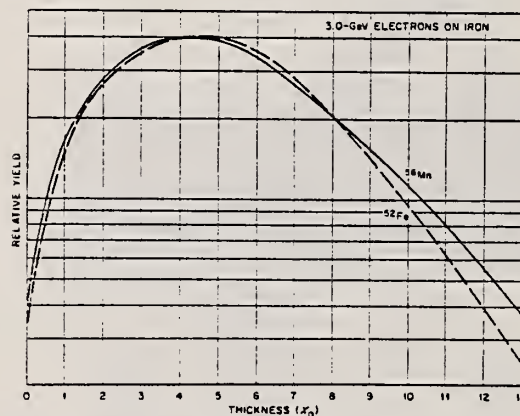


FIG. 2. Relative yields of ^{56}Mn and ^{52}Fe in a thick iron target bombarded with 3.0-GeV electrons. The curves are normalized at the peaks.

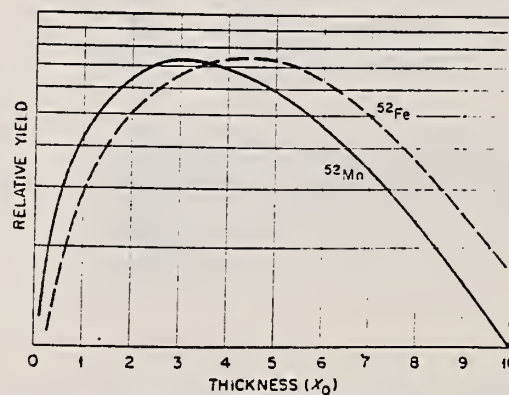


FIG. 4. Relative yields of ^{52}Fe and ^{52}Mn in a thick iron target bombarded with 3.0-GeV electrons. The curves are normalized at the peaks.

(over)

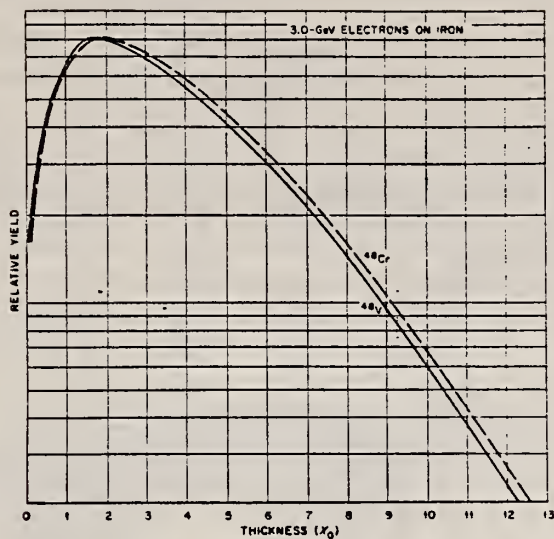


FIG. 3. Relative yields of ^{48}Cr and ^{48}V in a thick iron target bombarded with 3.0-GeV electrons. The curves are normalized at the peaks.

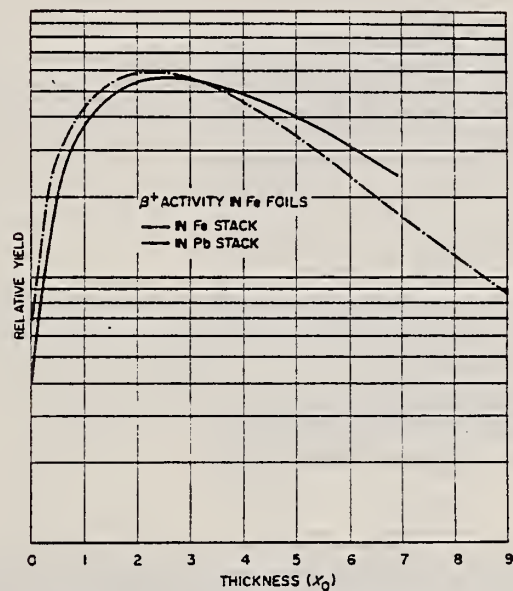


FIG. 7. Relative β^+ activity produced in iron foils in thick targets bombarded with 3.0-GeV electrons.

REF. C. B. Fulmer, K. S. Toth, I. R. Williams, T. H. Handley,
G. F. Dell, E. L. Callis, T. M. Jenkins, and J. M. Wyckoff
Phys. Rev. C2, 1371 (1970)

ELEM. SYM.	A	Z
Fe		26

METHOD

REF. NO.	
70 Fu 1	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,F	RLY	999	D	999	ACT-D		4PI

Evidence of a fissionlike process for nuclides with a mass < 35.

999 = 1.5-16.0 GEV

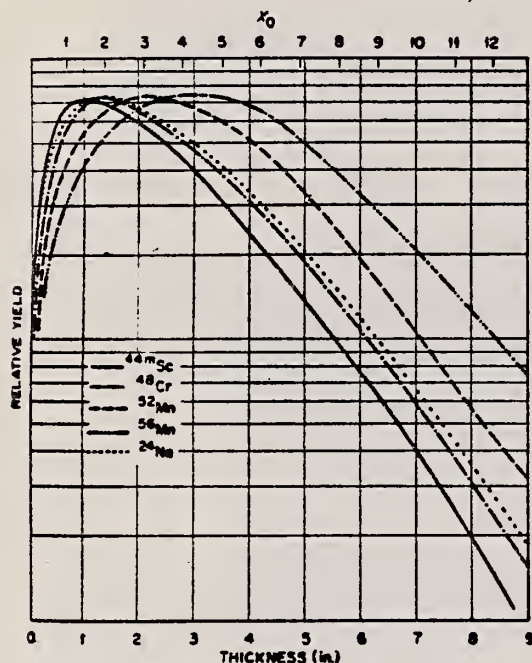


FIG. 2. Relative yields of some nuclides produced in a thick iron target bombarded with 3.0-GeV electrons. The curves are normalized to the same ordinate value at the peaks.

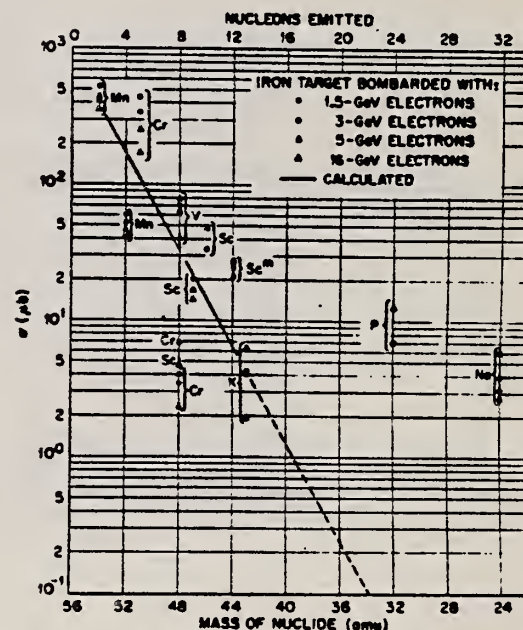


FIG. 1. Yields of radionuclides identified in iron samples that were exposed to beams of 1.5- to 16-GeV electrons. The values of σ are based on the integrated electron beam intensity. The "calculated" line is, in reality, a "calculated slope" as is described in the text.

TABLE I. Ratio of yields of nuclides used to determine values of K . ^{44}Sc yields include 4.0-h ^{44}Sc and 2.4-day ^{44}Sc , which for the 1.5-, 3.0-, and 5.0-GeV data were assumed to be twice the yield of ^{44}Sc .

Energy (GeV)	Target	Nuclides	Ratio of yields (experimental)	$\Delta Z_1 - \Delta Z_2$	K
1.5	iron	$^{51}\text{Cr}/^{44}\text{Sc}$	6.2	3	1.96
3.0	iron	$^{51}\text{Cr}/^{44}\text{Sc}$	8.4	3	2.03
5.0	iron	$^{51}\text{Cr}/^{44}\text{Sc}$	5.95	3	1.32
16	iron	$^{51}\text{Cr}/^{44}\text{Sc}$	4.0	3	1.58
16	aluminum	$^{22}\text{Na}/^{18}\text{F}$	2.7	2	1.64
0.32	arsenic		(Halpern <i>et al.</i>) ^a		2.3

^aSee Ref. 19. I. Halpern, R. J. Debs, J. T. Eisinger, A. W. Fairhall, and H. G. Richter, Phys. Rev. 97, 1327 (1955).

[over]

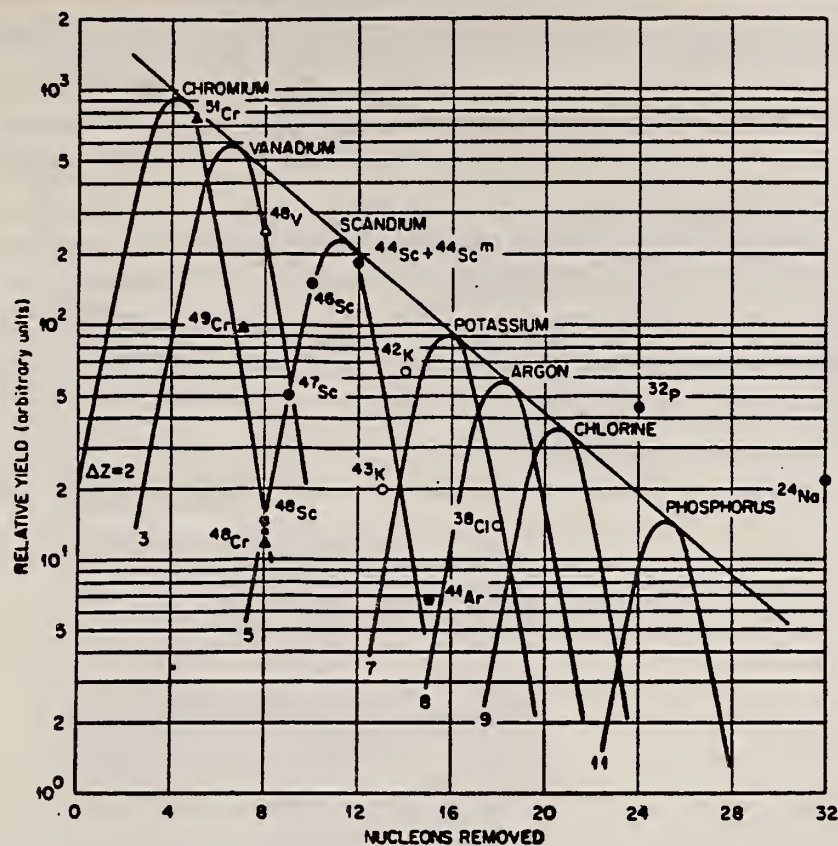


FIG. 3. Yields of radionuclides observed in a thin iron target bombarded with 16.0-GeV electrons versus the number of nucleons removed. The abscissa scale refers to ^{56}Fe .

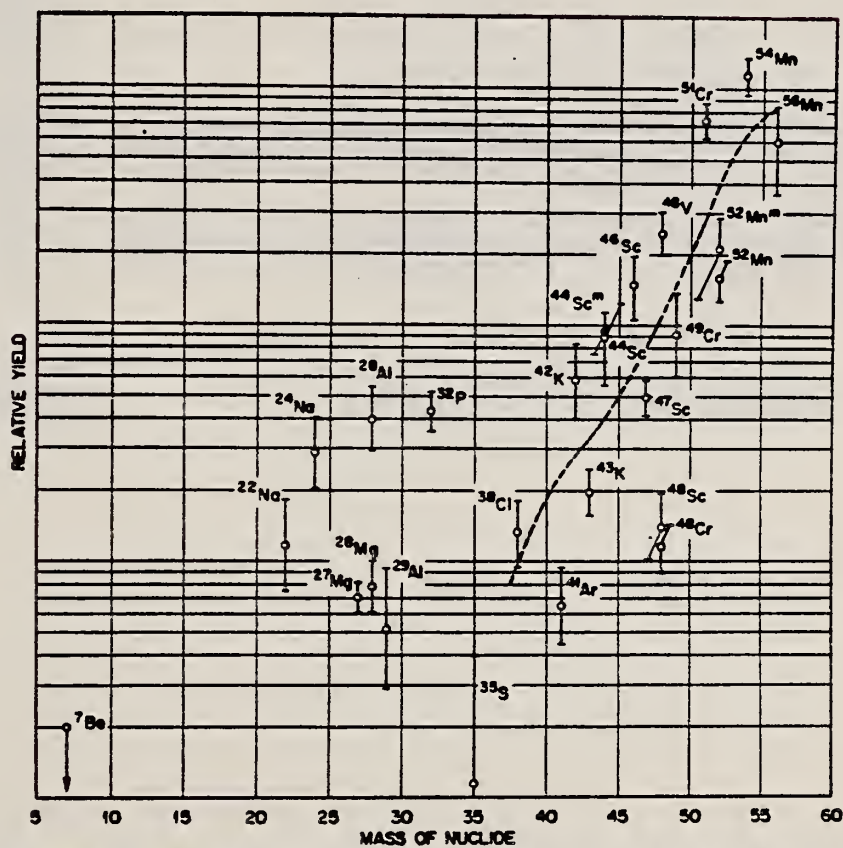


FIG. 5. Yield of radionuclides observed in a thin iron target bombarded with 16-GeV electrons versus mass of the nuclide. The dashed curve is the prediction of a nuclear evaporation theory (Ref. 20).

METHOD

REF. NO.

71 Co 2

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABI	36-64	C	10-64	BF3-I		4PI

FAST N YIELD

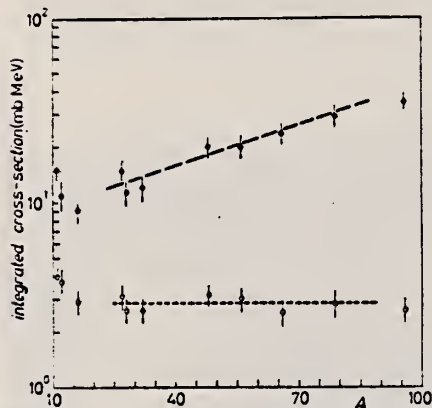


Fig. 2.

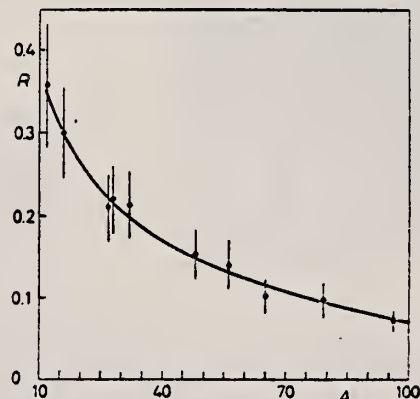


Fig. 3.

Fig 2. - Experimental photoneutron cross-sections integrated over photon energy between 36 and 64 MeV and divided by NZ/A are plotted as a function of the mass number. Black dots are total cross-sections not corrected for neutron multiplicity; open circles represent fast neutron cross-sections (see text). The dashed lines are drawn only to guide the eye.

Fig. 3. - The ratio between "fast" and total photoneutron integrated cross-sections as a function of the mass number A . The solid line represents a fit of the ratios calculated for some nuclei by taking into account the theoretical neutron energy spectra given by GABRIEL and ALSMILLER (4) and the efficiencies of our detector (see Fig. 1).

METHOD

REF. NO.

71 Fu 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, SPL	ABI	THR-999	D	40-999	SCD-D		4PI

999 = 16 GEV

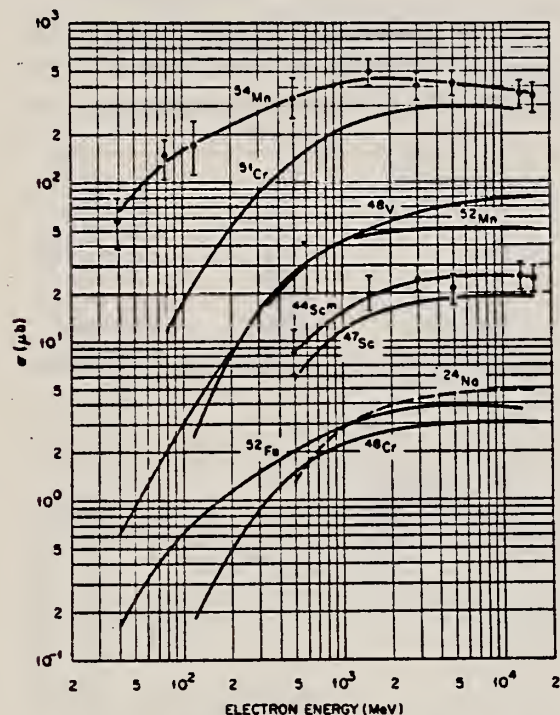


FIG. 1. Yields of some nuclides produced in thin iron targets bombarded with electrons. The yields are plotted as cross sections based on the integrated intensity of the electron beams used.

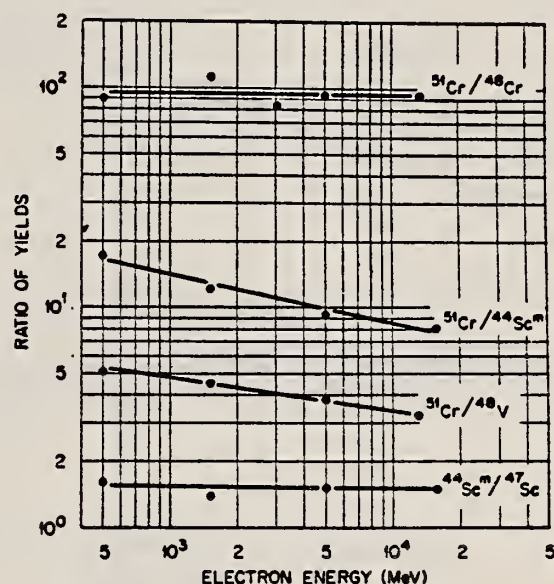


FIG. 2. Ratios of yields of pairs of nuclides produced in thin iron targets bombarded with electrons.

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
71 Fu 4	hmg	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SPL	RLX	THR-999	D	999	ACT-I		4PI
		(5 GEV)		(5 GEV)			

Measurement of F values (the ratio of photo-disintegration to electrodisintegration cross sections).

999= 5 GEV

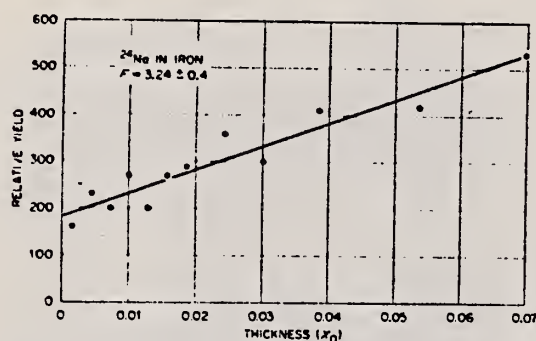


FIG. 3. Relative yields vs target thickness of ^{24}Na in an iron target bombarded with 5-GeV electrons.

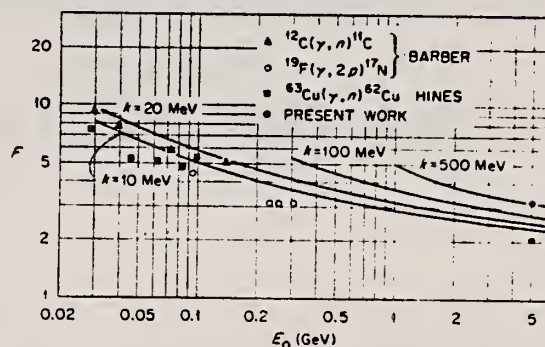


FIG. 5. Calculated F values for $E1$ excitation in iron as a function of incident electron energy. The experimental data for ^{63}Cu are presented in Ref. 1; the experimental data for ^{12}C and ^{19}F are presented in Ref. 3.

TABLE I. Experimentally measured F values for several nuclides produced in targets bombarded with 5-GeV electrons.

Target	Nuclide	F
Aluminum	^{24}Na	2.4 ± 0.4
Aluminum	^{7}Be	3.3 ± 0.5
Iron	^{52}Mn	2.0 ± 0.3
Iron	^{48}Cr	2.0 ± 0.2
Iron	^{44}Sc	2.4 ± 0.4
Iron	^{24}Na	3.2 ± 0.4
Tantalum	^{175}Hf	2.0 ± 0.3
Tantalum	^{177}Lu	1.9 ± 0.4

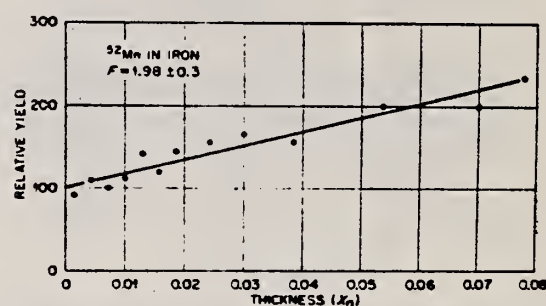


FIG. 1. Relative yields vs target thickness of ^{52}Mn in an iron target bombarded with 5-GeV electrons.

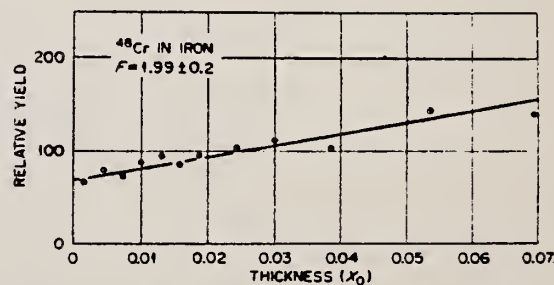


FIG. 2. Relative yields vs target thickness of ^{48}Cr in an iron target bombarded with 5-GeV electrons.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SPL	ABY	THR-999	C	999	ACT- I		4PI

$\sigma_q(A, Z) = K \exp [PA - R(A - SZ + TZ^2)^2]$, cross section per equivalent quantum.

999 = 1.5 GEV

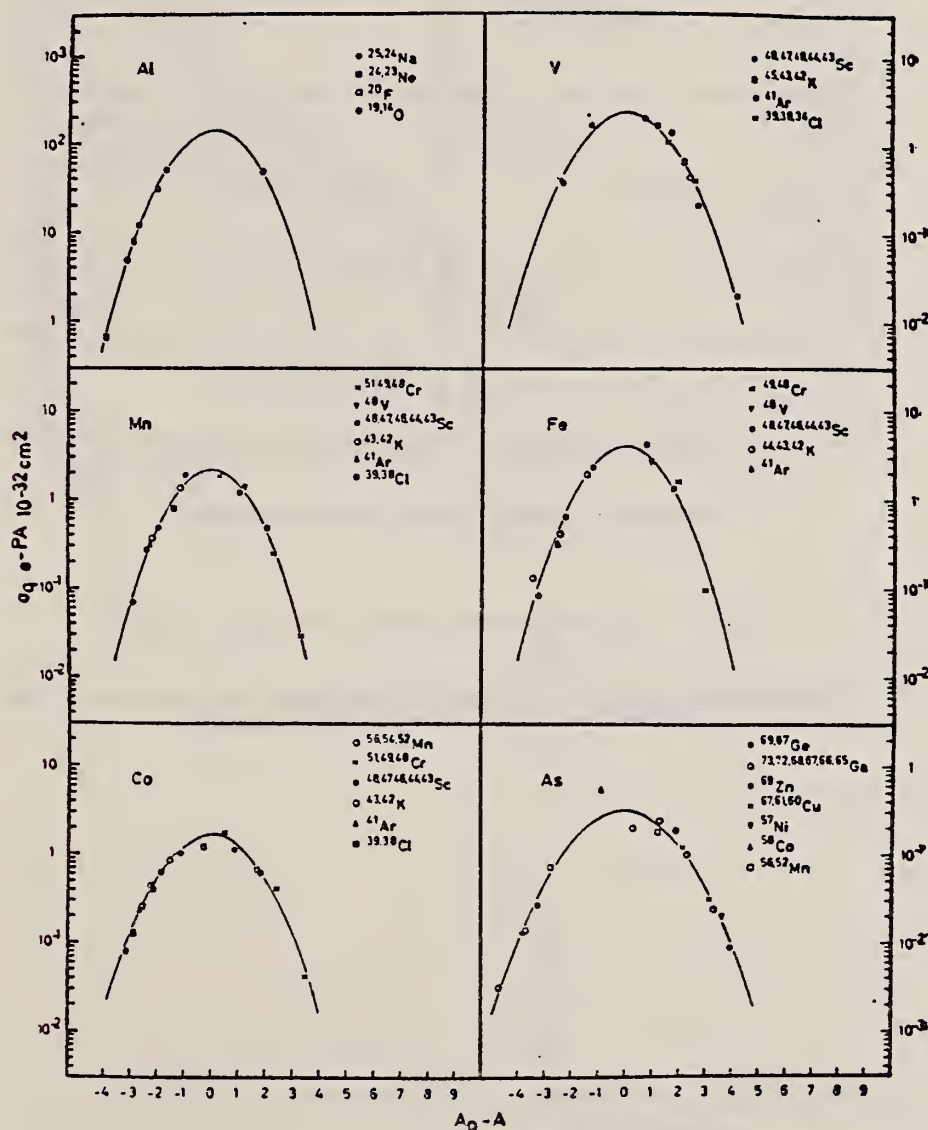


Fig. 4. Yield distributions from various targets with bremsstrahlung of 1.5 GeV.

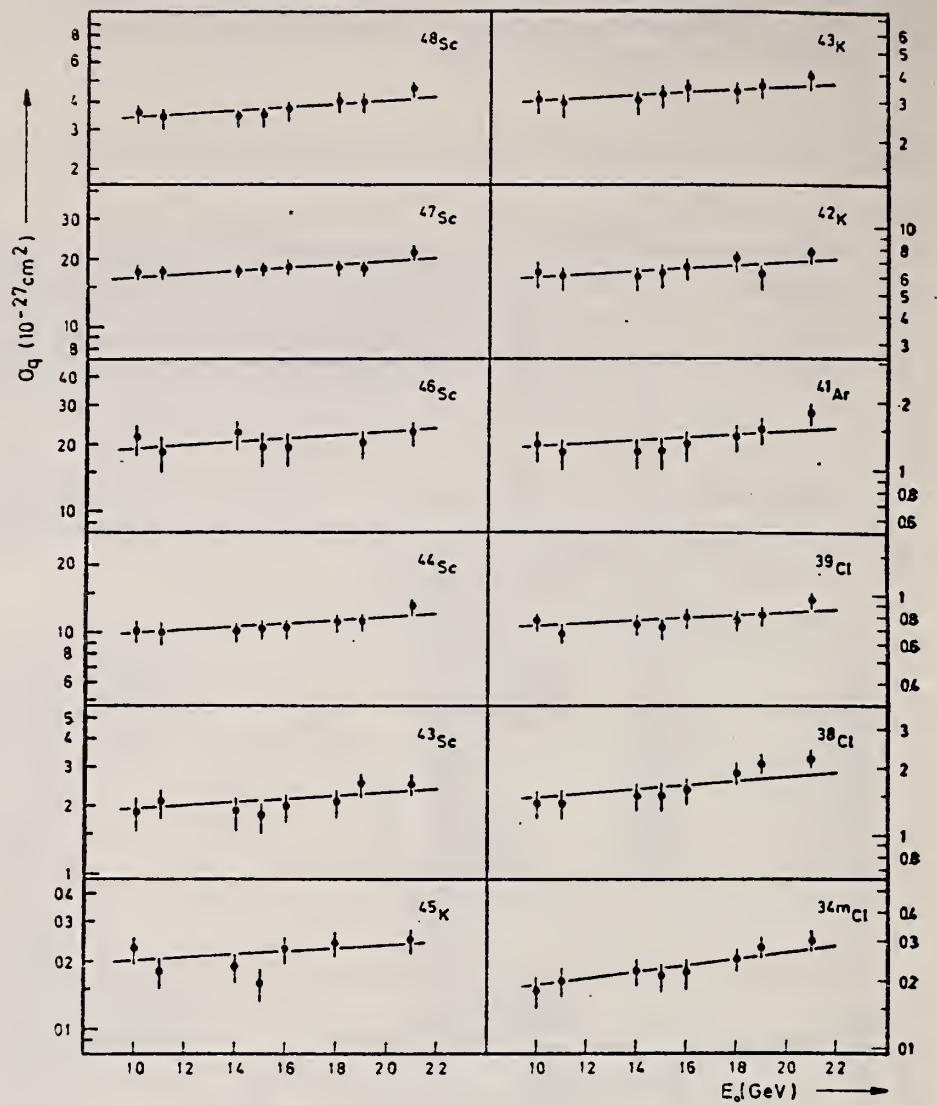


Fig. 5. Yields of spallation products using vanadium targets.

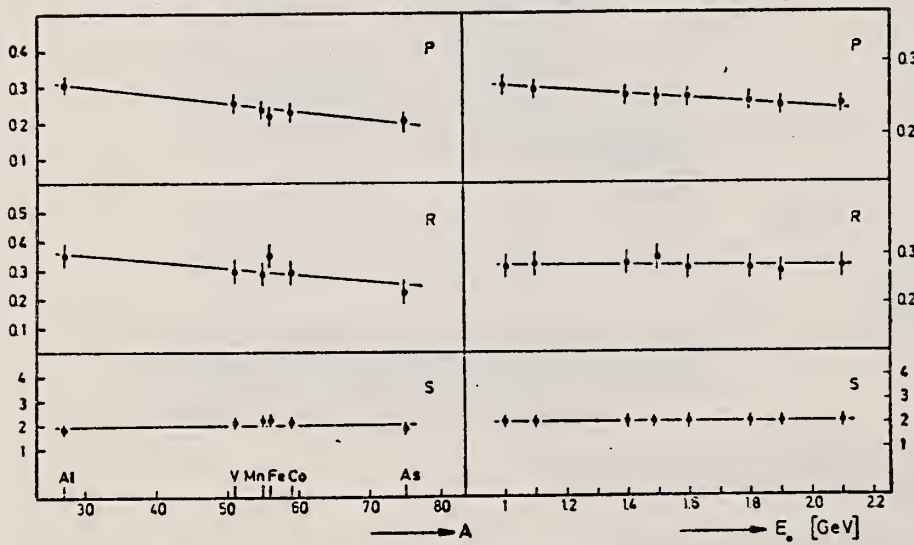


Fig. 6. Behaviour of the parameters P , R and S as functions of A and E_0 .

REF.

G. Kumbartzki and U. Kim
Nucl. Phys. A176, 23 (1971)

ELEM. SYM.

A

Z

Fe

26

METHOD

REF. NO.

71 Ku 5

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
* G, SPL	ABY	THR-999	C	999	ACT-I		4PI
** G, PI+	ABY	THR-999	C	200-999	ACT-I		4PI

* 999= 1.5 GEV

** 999= 2.2 GEV

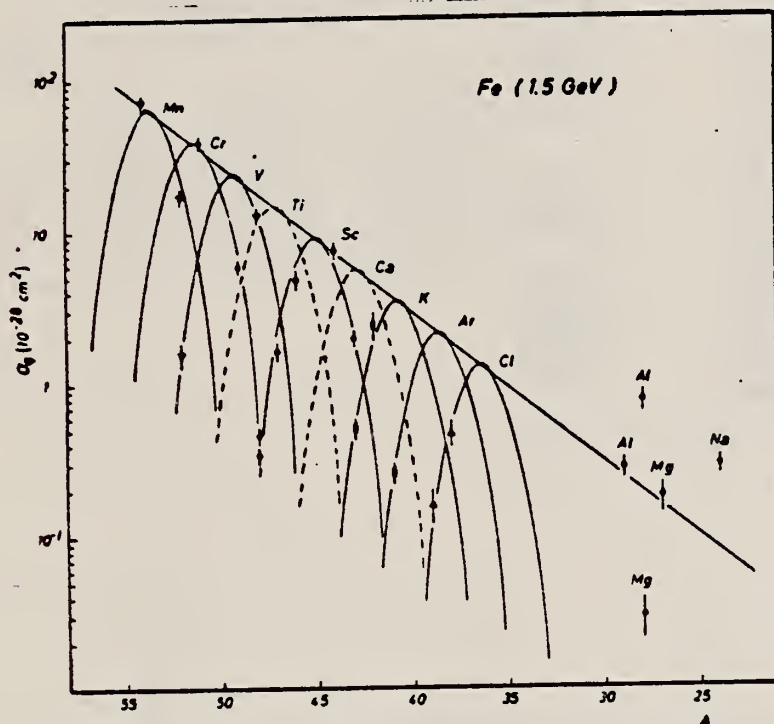


Fig. 3. Photonuclear yields obtained from iron target with 1.5 GeV bremsstrahlung are plotted as a function of the mass number A of the residual nuclei.

(over)

TABLE I
Decay data and yields of radioactive nucleides in vanadium and iron at 1.5 GeV
bremsstrahlung energy

Nuclide	Half-life	Gamma energy (keV)	Intensity	$\sigma_0 (10^{-28} \text{ cm}^2)$ (vanadium)	$\sigma_0 (10^{-28} \text{ cm}^2)$ (iron)
⁵³ Fe	8.6 min	380.0	32		12.6 ± 1.6
⁵² Fe	8.2 h	168.1	100		0.40 ± 0.05
⁵⁶ Mn	2.57 h	846.7	100		3.5 ± 0.4
⁵⁴ Mn	312 d	834.8	100		72.0 ± 9.0
^{52m} Mn	21 min	1434.4	98		9.1 ± 1.0
⁵² Mn	5.7 d	1434.4	100		7.9 ± 0.9
⁵¹ Cr	27.8 d	320.1	9		39 ± 4
⁴⁹ Cr	42 min	153.6	13	0.77 ± 0.09	5.9 ± 0.6
⁴⁸ Cr	23 h	307.8	99		0.46 ± 0.6
⁴⁸ V	16 d	983.7	100	10.2 ± 1.3	12.8 ± 1.4
⁵² V	3.8 min	1434.4	100		1.6 ± 0.3
⁵¹ Ti	5.8 min	320.1	95	0.31 ± 0.07	
⁴⁸ Sc	1.83 d	1038.5	100	3.49 ± 0.43	0.34 ± 0.06
⁴⁷ Sc	3.4 d	159.4	70	18.2 ± 2.7	1.63 ± 0.20
⁴⁶ Sc	83.9 d	1120.0	100	19.4 ± 3.3	4.8 ± 0.7
^{44m} Sc	2.44 d	270.8	86	5.2 ± 0.7	3.8 ± 0.4
⁴⁴ Sc	3.92 h	1156.9	100	5.2 ± 0.8	4.1 ± 0.5
⁴³ Sc	3.92 h	372.8	22	1.8 ± 0.2	1.9 ± 0.3
⁴³ K	22.4 h	617.2	81	3.1 ± 0.4	0.51 ± 0.08
⁴² K	12.4 h	1524.7	18	6.2 ± 0.9	2.4 ± 0.5
⁴⁴ K	22 min	1156.9	61	1.7 ± 0.3	
⁴³ K	20 min	175	80	0.20 ± 0.05	
⁴¹ Ar	1.83 h	1293.0	99	1.24 ± 0.23	0.26 ± 0.04
³⁹ Cl	55.5 min	1266.4	50	0.71 ± 0.12	0.16 ± 0.04
³⁸ Cl	37.3 min	1642.2	33	1.47 ± 0.21	0.48 ± 0.09
^{34m} Cl	32 min	147.2	45	0.21 ± 0.04	
²⁹ Al	6.6 min	1273.1	94	0.41 ± 0.09	0.28 ± 0.08
²⁸ Al	2.3 min	1778.7	100	0.86 ± 0.15	0.78 ± 0.12
²⁸ Mg	21 h	1342.0	70	0.09 ± 0.03	0.03 ± 0.01
²⁷ Mg	9.5 min	843.2	70	0.42 ± 0.07	0.18 ± 0.04
²⁴ Na	15 h	1368.5	100	0.51 ± 0.08	0.29 ± 0.04
²⁴ Ne	3.4 min	472.0	100	0.04 ± 0.01	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,A	RLY	7-32	C	32	SCD-D		DST

TABLE 3. Observed angular distribution parameters for 32 MeV electron energy

Element	A_0	A_1/A_0	A_2/A_0
Ti	7.03 ± 0.15	0.073 ± 0.052	-0.286 ± 0.073
V	2.58 ± 0.06	0.037 ± 0.042	-0.126 ± 0.069
Fe	10.22 ± 0.30	0.006 ± 0.043	-0.333 ± 0.072
Co	6.80 ± 0.20	0.022 ± 0.048	$+0.016 \pm 0.077$
Ni	15.95 ± 0.49	0.051 ± 0.048	-0.213 ± 0.074
Cu	8.37 ± 0.28	0.076 ± 0.056	-0.035 ± 0.081
Zn	17.87 ± 0.61	0.004 ± 0.045	-0.270 ± 0.073
Ag	0.39 ± 0.01	0.115 ± 0.049	$+0.093 \pm 0.074$

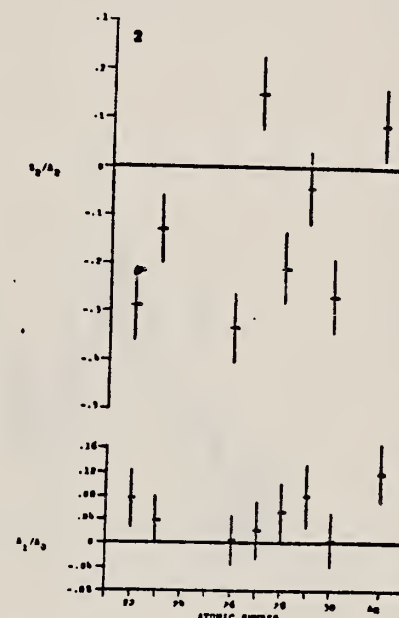


FIG. 2. Angular distributions for 32 MeV electron energy.

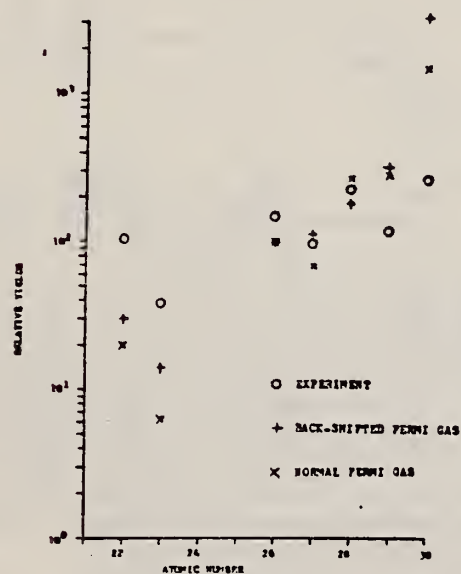


FIG. 13. Experimental and theoretical relative photo-alpha yields for 32 MeV electron beam energy.

ELEM. SYM.	A	Z
Fe		26
REF. NO.	73 Ba 20	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NOX	THR- 27	C	10- 27	BF3-I		4PI

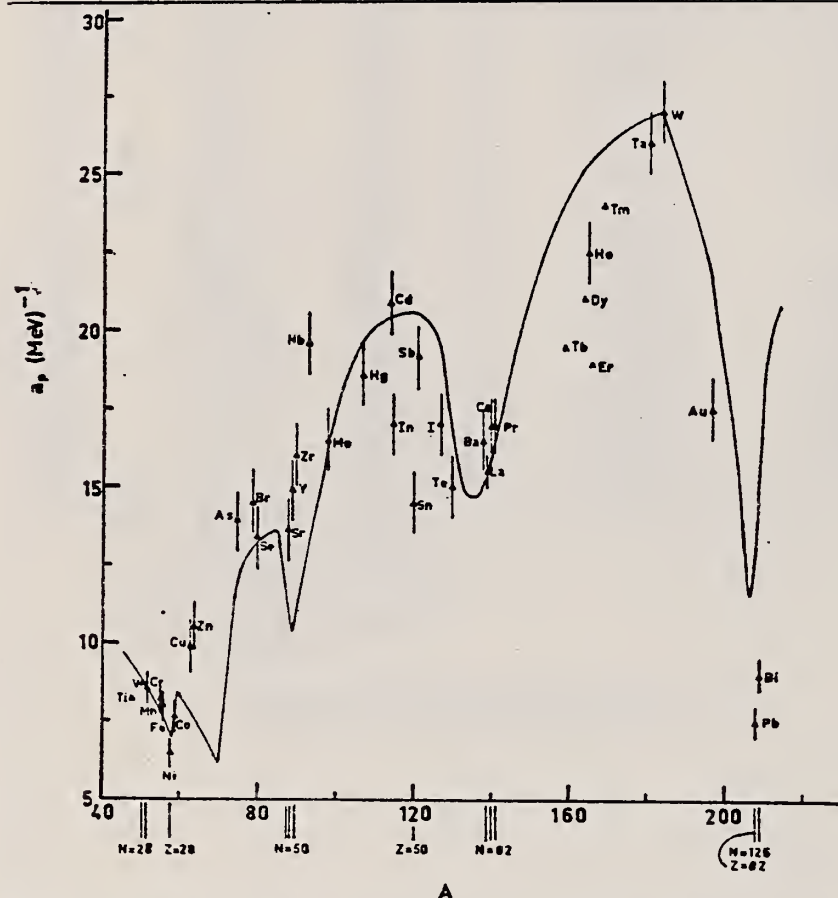


Fig. 12. Experimental values of the level density parameter a_p (Fermi gas formula plus pairing correction) versus atomic number A . The continuous curve is a least-squares fit to the data of a theoretical calculation from Newton ¹⁵.

- 1 H. Baba and S. Baba, Japan Atomic Energy Research Institute report JAERI-1183 (1969).
- 2 H. Baba, Nucl. Phys. A159, 625 (1970).
- 15 T.D. Newton, Can. J. Phys. 34, 804 (1956).

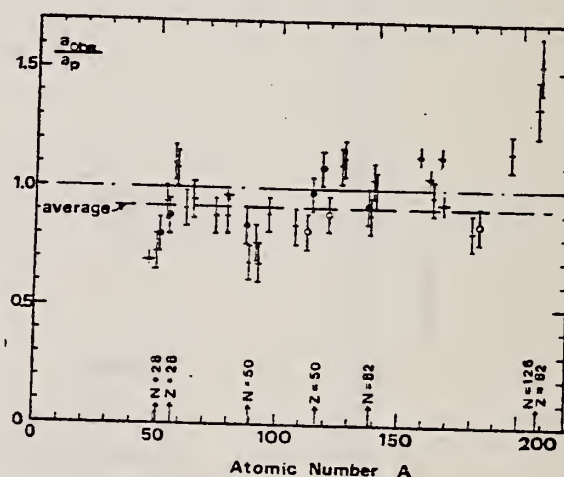


Fig. 15. Ratio a_{obs}/a_p versus atomic number A . Here a_{obs} is the level density parameter taken from the neutron resonance work of refs. ^{1,2}, and a_p is the level density parameter derived from the present (γ, n) work. Filled circles represent points where nuclei in the neutron resonance and in the (γ, n) experiment were the same. Open circles represent points where the respective nuclei were approximately matched. Triangles represent points which are based on measurement of neutron mean energies at two bremsstrahlung energies only.

(over)

TABLE 3

Comparison of experimental and theoretical data on nuclear level densities with Fermi gas formulae, and comparison of nuclear level density parameters from (γ, n) and n-resonance absorption experiments

Target	N (residual nucleus) ^{a)}		Goodness of fit ^{b)}		$\bar{E}_n(24)$ (MeV) ^{c)}	T (MeV) ^{d)}	a_p (MeV ⁻¹) ^{e)}	a_{obs} (MeV ⁻¹) ^{f)}	a_{obs}/a_p
			no	with					
			p.c.	p.c.					
Ti ^{g)}	23	8%			1.93		8.1- ⁴⁷ Ti	6.41- ⁴⁷ Ti	0.79
	24	8%							
	25	73%							
	26	5%							
	27	5%							
V ^{g)}	27	100%			1.96		8.7- ⁵⁰ V	6.35- ⁵¹ V	0.73
Cr	25	4%	P	G	1.89		8.6- ⁵¹ Cr	6.9 - ⁵¹ Cr	<u>0.80</u>
	27	84%							
	28	10%							
	29	2%							
Mn	29	100%	V.P.	G	2.1		8.2- ⁵⁴ Mn	7.82- ⁵⁶ Mn	0.94
Fe	27	6%	F	G	1.96		8.0- ⁵⁵ Fe	7.06- ⁵⁵ Fe	<u>0.88</u>
	29	92%							
	30	2%							
Co	31	100%	P	F	2.12		7.7- ⁵⁸ Co	8.35- ⁶⁰ Co	1.08
Ni (Z = 28)	29	68%	V.P.	P	2.04	1.4	6.5- ^{57.7} Ni	7.19- ⁵⁹ Ni	1.10
	31	26%							
	32	1%							
	33	4%							
	35	1%							
Cu	33	69%	V.P.	P	1.78	1.0	9.8- ⁶² Cu	8.90- ⁶⁴ Cu	0.91
	35	31%							
Zn	33	49%	F	F	1.61		10.5- ^{64.4} Zn	10.0- ⁶⁵ Zn	0.95
	35	28%							
	36	4%							
	37	19%							
As	41	100%	V.P.	F	1.44		14.5- ⁷⁴ As	12.81- ⁷⁶ As	0.88
Se ^{g)}	41	9%			1.39		13.3- ⁷⁸ Se	12.8 - ⁷⁸ Se	<u>0.97</u>
	42	8%							
	43	24%							
	45	50%							
	47	9%							
Br	43	45%	V.P.	V.P.	1.41		14.5- ⁷⁹ Br	12.69- ⁸⁰ Br	0.88
	45	49%							
Sr	47	10%	F	G	1.31		13.6- ⁸⁷ Sr	11.4 - ⁸⁷ Sr	<u>0.84</u>
	48	7%							
	49	83%							

^{a)} Neutron numbers and abundances of respective residual nuclei in (γ, n) experiments.

^{b)} These give an assessment of the goodness of fit of a calculated \bar{E}_n versus E_0 curve to the observed data, using the Fermi gas level density formula both without and with pairing corrections.

^{c)} Bremsstrahlung photoneutron mean energies \bar{E}_n for peak bremsstrahlung energy $E_0 = 24$ MeV.

^{d)} Nuclear temperature from fit with constant-temperature formula.

^{e)} Level density parameter a_p derived from the present (γ, n) experiment, using a Fermi gas formula plus pairing correction, and corresponding residual nucleus (the atomic weight shown is the weighted average of atomic weights of the respective isotopes present).

^{f)} As column 7, but using data on n-resonance absorption from refs. ^{1, 2}).

^{g)} Measurements of $\bar{E}_n(E_0)$ for these nuclei were made only for $E_0 = 21, 23$ and 24 MeV.

REF.

A. I. Abramov, V. Ya. Kitaev, M. G. Yutkin
Yad. Fiz. 20, 438 (1974)
Sov. J. Nucl. Phys. 20, 236 (1975)

ELEM. SYM.	A	Z
Fe		26
REF. NO.		74 Ab 11
		hmg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, N	ABX	11 - 13	C	11, 13	TOF-D		78
		(11.2-12.5)		(11.5, 12.5)			

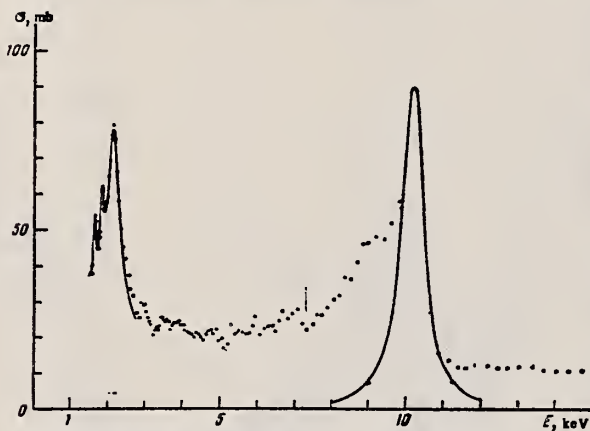


FIG. 3. Differential cross sections for the (γ, n) reaction in iron, measured for $E_{\gamma}^{\max} = 12.5$ MeV at an angle of 70° and multiplied by 4π ; the smooth curve is a fit by the Breit-Wigner formula (in the vicinity of the peak at ~ 10 keV the experimental points lie satisfactorily on a Breit-Wigner curve).

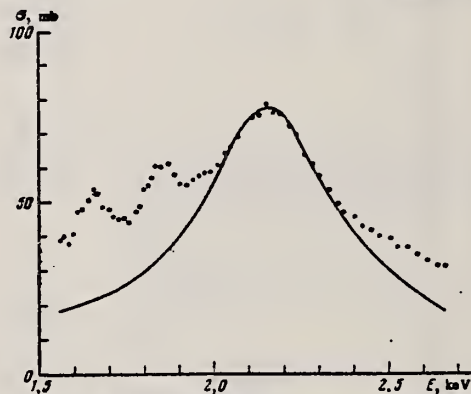
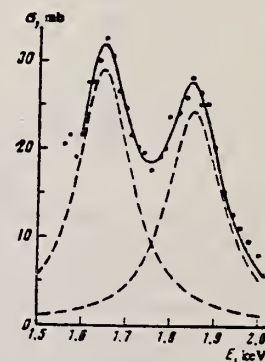


FIG. 4. The same data as in Fig. 3 in the neutron-energy region from 1.5 to 3 keV. The solid curve shows the result of describing the resonance at $E_L^0 = 2.16$ keV by a Breit-Wigner formula with a constant component $\sigma_C = 10$ mb.

TABLE I

E_L^0 , keV		E_C^0 , keV		E_L^0 , keV		E_C^0 , keV	
Present work	[1], [2]	Present work	[1], [2]	Present work	[1], [2]	Present work	[1], [2]
—	1.05	—	1.28	—	14.7	—	15.9
1.65	1.25	1.62	1.51	20.5	21.0	20.6	22.3
1.86	1.65	1.83	1.94	—	23.5	—	24.9
2.16	1.92	2.13	2.22	26.5	—	26.7	—
—	2.20	—	2.54	—	27.0	—	28.5
—	2.95	—	2.95	31.6	31.0	31.8	32.6
—	3.40	—	3.40	43.5	(43)	44.0	(45.1)
—	4.0	—	4.0	49.8	(50)	50.0	(52.4)
—	5.35	—	5.35	63.8	—	64.5	—
6.85	—	6.83	—	—	83.1	—	86.6
9.59	8.80	9.59	9.55	—	97.6	—	101.5
10.15	9.80	10.16	10.62	103.6	105	111	109
—	10.65	—	11.5	—	124	—	129
—	11.30	—	12.2	136	132	138	137

FIG. 5. Results of analysis of the resonances at $E_L^0 = 1.65$ and 1.86 keV.



- ²C.D. Bowman et al., Phys. Rev. 163, 951 (1967)
⁴R.J. Baglan et al., Phys. Rev. C3, 672 (1971)

TABLE II

E_L^0 , keV	I , eV		σ_n , mb		σ_{γ} , Γ_{γ} , eV	
	Present work	[1]	Present work	[1]	Present work	[1]
1.65	145 ± 32	—	29.6 ± 4.2	—	0.11 ± 0.03	—
1.86	146 ± 27	—	24.7 ± 2.7	—	0.092 ± 0.019	—
2.16	451 ± 78	415	68 ± 12	75	0.79 ± 0.18	0.80
10.15	538 ± 54	560^{+100}_{-80}	118 ± 15	136	1.82 ± 0.23	1.93

REF.

A.I. Abramov, V.Ya. Kitaev, and M.G. Yutkin
 Izv. Akad. Nauk SSSR. Ser. Fiz. 38, 2112 (1974)
 Bull. Acad. Sci. USSR Phys. Ser. 38, 85 (1974)

ELEM. SYM.

A

Z

Fe

26

METHOD

REF. NO.

74 Ab 12

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	11- 13	C	11, 13	TOF-D		78
		(11.2-12.5)		(11.5,12.5)			

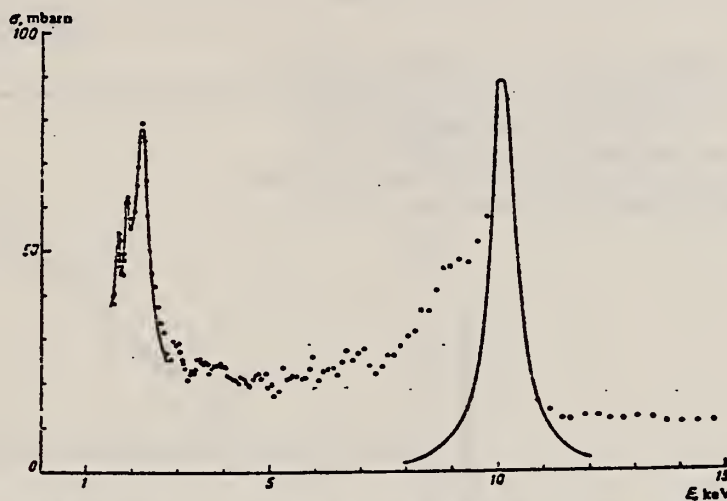


Fig. 2. Differential (γ , n) cross sections for iron at $E_{\gamma}^{\max} = 12.5$ MeV at 78° and multiplied by 4π .

TABLE 1

Energy Levels of ^{56}Fe

E_L^0 , keV	E_c , keV		E, MeV^{**}	E_L^0 , keV	E_c , keV		E, MeV^{**}
	our results	[1, 2] *			our results	[1, 2] *	
1.65	1.62	1.51	11,2036	26.5	26.7	—	11,229
1.86	1.83	1.94	11,2039	31.6	31.8	32.6	11,234
2.16	2.13	2.22	11,2042	43.5	44.0	(45,1)	11,247
6.85	6.83	—	11,2089	49.8	50.0	(52,4)	11,253
9.59	9.59	9.55	11,2118	63.8	64.5	—	11,268
10.15	10.16	10.62	11,2124	109.6	111	109	11,313
20.5	20.6	22.3	11,223	136	138	137	11,342

*The results of [1, 2] have been taken selectively. The values in parentheses are for levels shown in the figures in [1] but without numerical data.
 **On the assumption that all the observed resonances relate to ^{56}Fe , for which $Q_n = 11.202$ MeV [9].

TABLE 2

Resonance Parameters of Four Levels of ^{56}Fe

E_L^0 , keV	Γ , eV		σ_0 , mbarn		$E_{\gamma, \gamma_{\text{res}}}$, eV	
	our results	[1]	our results	[1]	our results	[1]
1.65	145 ± 32	—	29.6 ± 4.2	—	0.11 ± 0.03	—
1.88	148 ± 27	—	24.7 ± 2.7	—	0.092 ± 0.019	—
2.16	451 ± 76	415	68 ± 12	75	0.79 ± 0.18	0.60
10.15	536 ± 54	560_{-50}^{+100}	118 ± 15	136	1.62 ± 0.23	1.93

REF.

M. Eriksson and G. G. Jonsson
Nucl. Phys. A242, 507 (1975)

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
75 Er 2		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SC44	ABY	THR-800	C	250-800	ACT-I		4PI

ISOMER RATIO

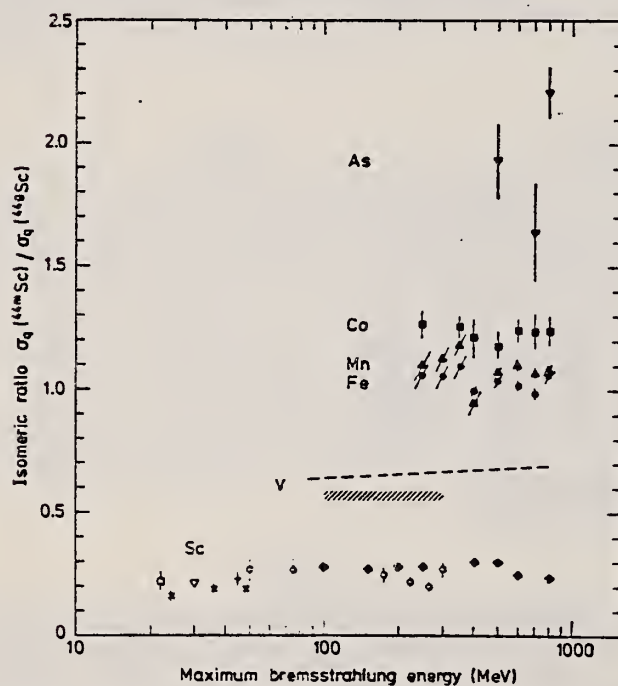


Fig. 6. Isomeric ratio $\sigma_3(^{44m}\text{Sc})/\sigma_q(^{44}\text{Sc})$ versus bremsstrahlung end-point energy for the different targets. Sc target: \diamond - this work, \square - ref. ¹⁵, \times - ref. ¹⁶, ∇ - ref. ¹⁷, $+$ - ref. ¹⁸, \circ - ref. ¹⁹; V target: dashed curve - ref. ²⁰, dashed area - ref. ²¹; Fe target: \bullet - this work; Mn target: \blacktriangle - this work; Co target: \blacksquare - this work; As target: \blacktriangledown - this work.

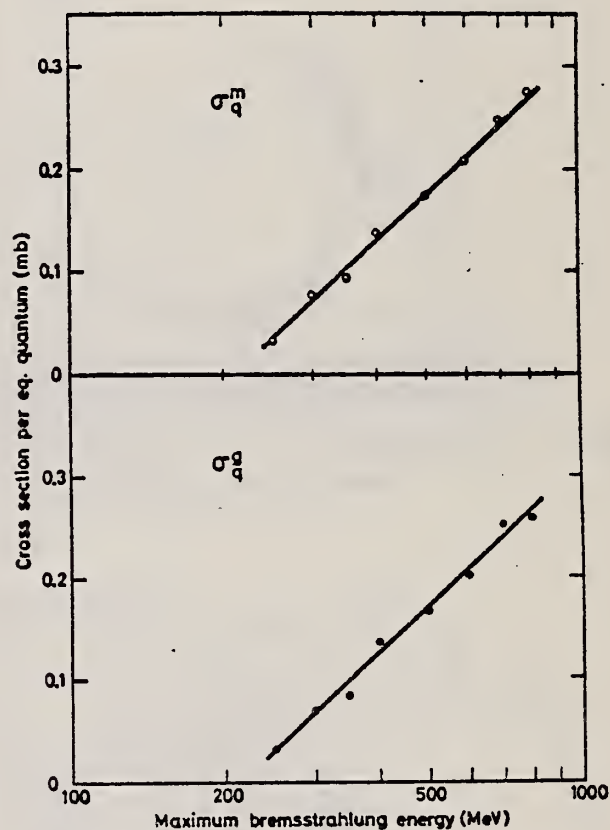


Fig. 4. Yield curves for the reaction $\gamma + \text{Fe} \rightarrow ^{44}\text{Sc}$.

(over)

TABLE 2
Comparison between experimental and calculated cross sections and isomeric ratios

Target	$\bar{\sigma}_{exp}$ (mb) 250-800 MeV	σ_{MC} (mb) 400 MeV	$\bar{\sigma}_{SE}$ (mb) 250-800 MeV	$\sigma(m)/\sigma(g)_{exp}$ 250-800 MeV	$\sigma(m)/\sigma(g)_{calc}$ 400 MeV
⁴⁵ Sc	≈ 0.5	0.58 ± 0.05		≈ 0	0.05
⁵¹ V	≈ 0.5	0.48 ± 0.05	0.47	0.7	0.72
⁵⁵ Mn	0.40 ± 0.14	0.59 ± 0.05	0.28	1.08 ± 0.04	1.04
Fe	0.40 ± 0.14		0.26	1.00 ± 0.05	
⁵⁹ Co	0.26 ± 0.10	0.34 ± 0.04 $0.65 \pm 0.07^*)$	0.18	1.26 ± 0.06	1.12 1.15 ^{*)}
⁷⁵ As		0.01 ± 0.01	0.044	1.9 ± 0.3	

*) 325 MeV.

- 15) S. A. Steinberg, B. Sc. thesis, Univ. of Illinois, 1963, unpublished (value taken from ref. 19))
- 16) J. R. Tatarczuk and H. A. Medicus, Phys. Rev. 143 (1966) 818
- 17) T. Kato and Y. Oka, Talanta 19 (1972) 515
- 18) R. Völpe, Nucl. Phys. A182 (1972) 411
- 19) W. B. Walters and J. P. Hummel, Phys. Rev. 150 (1966) 867
- 20) B. Bülow, Lund, private communication (preliminary results)
- 21) R. A. Meyer, thesis, Univ. of Illinois, 1963, unpublished

REF.

V. Emma, S. Lo Nigro, C. Milone
Nucl. Phys. A257, 438 (1976)

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
76 Em 2		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, F	ABY	THR-999	C	999	TRK-I		4PI

TABLE 1

999 = 1 GEV

Measured values of σ_q at $E = 1000$ MeV and deduced values of σ_k assumed constant from E_0 to 1000 MeV

Element	Z^2/A	σ_q (mb)	E_0 (MeV)	σ_k (mb)
Bi	32.96	12.3 ± 0.6	200	7.6 ± 0.6
Pb	32.45	5.4 ± 0.4	220	3.6 ± 0.3
Tl	32.10	4.1 ± 0.3	230	2.8 ± 0.3
Au	31.68	2.0 ± 0.15	240	1.4 ± 0.2
Pt	31.18	1.1 ± 0.08	255	$(8 \pm 0.7) \times 10^{-1}$
Re	30.21	$(3.7 \pm 0.3) \times 10^{-1}$	280	$(2.9 \pm 0.3) \times 10^{-1}$
W	29.78	$(3.5 \pm 0.3) \times 10^{-1}$	290	$(2.8 \pm 0.3) \times 10^{-1}$
Ta	29.45	$(3.3 \pm 0.3) \times 10^{-1}$	300	$(2.7 \pm 0.3) \times 10^{-1}$
Hf	29.04	$(1.7 \pm 0.2) \times 10^{-1}$	310	$(1.4 \pm 0.2) \times 10^{-1}$
Yb	28.31	$(1.3 \pm 0.1) \times 10^{-1}$	330	$(1.2 \pm 0.1) \times 10^{-1}$
Tm	28.18	$(7.5 \pm 0.8) \times 10^{-2}$	335	$(6.8 \pm 0.8) \times 10^{-2}$
Ho	27.21	$(3.6 \pm 0.4) \times 10^{-2}$	355	$(3.5 \pm 0.4) \times 10^{-2}$
Dy	26.80	$(2.6 \pm 0.3) \times 10^{-2}$	360	$(2.5 \pm 0.3) \times 10^{-2}$
Tb	26.58	$(2.5 \pm 0.3) \times 10^{-2}$	370	$(2.5 \pm 0.3) \times 10^{-2}$
Gd	26.04	$(1.6 \pm 0.2) \times 10^{-2}$	380	$(1.7 \pm 0.2) \times 10^{-2}$
Sm	25.56	$(1.3 \pm 0.2) \times 10^{-2}$	390	$(1.4 \pm 0.2) \times 10^{-2}$
Nd	24.96	$(9.2 \pm 0.9) \times 10^{-3}$	405	$(1 \pm 0.1) \times 10^{-2}$
Ce	24.00	$(8 \pm 0.9) \times 10^{-3}$	420	$(9 \pm 1) \times 10^{-3}$
La	23.39	$(8.4 \pm 0.9) \times 10^{-3}$	430	$(1 \pm 0.1) \times 10^{-2}$
Sb	21.36	$(1.2 \pm 0.2) \times 10^{-2}$	460	$(1.5 \pm 0.3) \times 10^{-2}$
Te	21.19	$(8.8 \pm 1) \times 10^{-3}$	465	$(1.2 \pm 0.2) \times 10^{-2}$
Sn	21.06	$(1.3 \pm 0.2) \times 10^{-2}$	465	$(1.7 \pm 0.3) \times 10^{-2}$
Cd	20.49	$(1.7 \pm 0.3) \times 10^{-2}$	470	$(2.2 \pm 0.4) \times 10^{-2}$
Ag	20.47	$(2 \pm 0.3) \times 10^{-2}$	470	$(2.6 \pm 0.4) \times 10^{-2}$
Zn	13.76	$(2 \pm 0.4) \times 10^{-1}$	515	$(3 \pm 0.6) \times 10^{-1}$
Cu	13.44	$(2.4 \pm 0.5) \times 10^{-1}$	515	$(3.6 \pm 0.8) \times 10^{-1}$
Ni	13.35	$(2.4 \pm 0.5) \times 10^{-1}$	510	$(3.6 \pm 0.8) \times 10^{-1}$
Fe	12.10	$(3 \pm 0.6) \times 10^{-1}$	510	$(4.4 \pm 0.9) \times 10^{-1}$

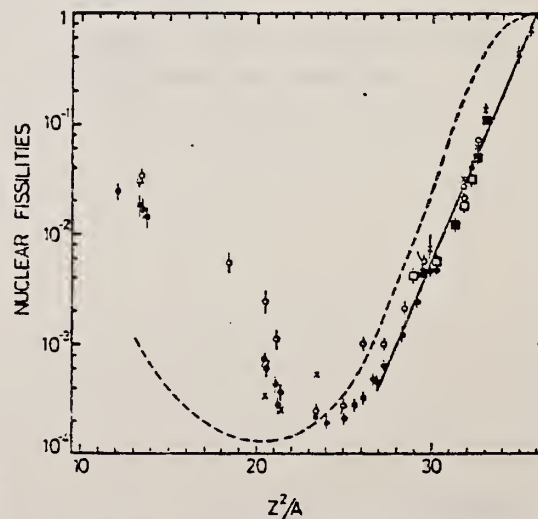
⁴ A.V. Mitrofanova et al.
Sov. J. Nucl. Phys. 6,
512 (1968).

⁷ T. Methasiri et al., Nucl.
Phys. A167, 97 (1971).

¹² J.R. Nix et al., Nucl. Phys.
81, 61 (1966).

²⁰ N.A. Perfilov et al., JETP
(Sov. Phys.) 14, 623 (1962);
Proc. Symp. on the physics &
chemistry of fission, Salzburg
1965, vol. 2 (IAEA) Vienna,
1965, p.283.

Fig. 2. Nuclear fissilities as a function of Z^2/A . Experimental points: solid circles represent our data; squares, the data from ref. ⁴); open circles, the data from ref. ⁷); and crosses, the data from (p,n) experiments²⁰). The straight line is the best fit calculated from our data for $Z^2/A > 26$. The dashed curve is the curve VI calculated by Nix and Sassi¹²).



REF.

V. Ya. Kitaev, A. I. Abramov, A. V. Rogov, and M. G. Yutkin
 Bull. of the Acad. of Sci. of the USSR. Phys. Series 40, 218
 Izvestiya Akademii Nauk SSSR. Seriya Fizicheskaya 40, 2274 (1976)

ELEM. SYM.

A

Z

Fe

26

METHOD

Remarks: Target 91.9% ^{58}Fe , 8.1% ^{57}Fe

REF. NO.

76 Ki 7

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	10- 11	C	11- 14	TOF-D	-	78
				(11.25-13.25)			

11.25-13.25 BREMS

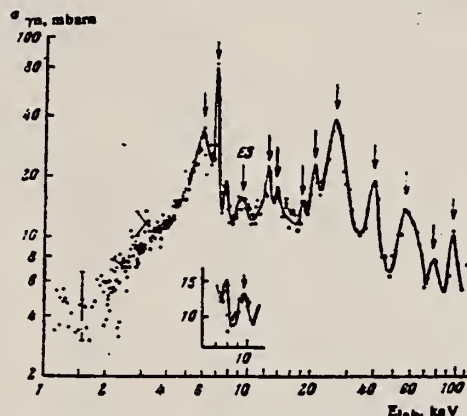


Fig. 1. Differential cross section of the (γn) reaction on ^{58}Fe measured for $E_Y^{\text{max}} = 13.25$ MeV and multiplied by 4π . The insert shows the results of measurements in the $E_n \sim 10$ keV region for $E_Y^{\text{max}} = 11.25$ MeV. The energies of the peaks are denoted by vertical arrows, and their values are given in the table. The index ES denotes the resonance caused by the transition to the excited level of the final ^{57}Fe nucleus.

TABLE 1

Energies of the Resonances (Peaks) in the Cross Sections of the $^{58}\text{Fe}(\gamma n)^{57}\text{Fe}$ and $^{57}\text{Fe}(n\gamma)^{58}\text{Fe}$ Reactions

E_{lab} keV (γn)	E_{calc} keV ($n\gamma$)	E_{exp} keV ($n\gamma$)	E_{lab} keV (γn)	E_{calc} keV ($n\gamma$)	E_{exp} keV ($n\gamma$)
—	—	1.63	21.3	21.4	21.3
—	—	3.92	27.0	27.2	29.0
—	—	4.75	41.0	41.4	41.0
6.25	6.24	6.21	—	—	45.5
7.20	7.19	7.22	—	—	55.8
7.85	7.85	7.90	58.0	58.6	81.0
9.70	9.72	—	78.5	79.4	77.2
12.70	12.70	12.80	—	—	93.7
13.9	14.0	13.9	98.0	99.2	109.6
18.6	18.7	17.7	—	—	110.15

Note. The calculated values are given in the center-of-mass system.

REF. V. di Napoli, F. Salvetti, M. L. Terranova, H. G. de Carvalho,
J. B. Martins, O. A. P. Tavares
J. Inorg. Nucl. Chem. 40, 175 (1978).

ELEM. SYM.	A	Z
Fe		26
REF. NO.		
78Di12	hg	

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,SPL	ABY	THR-999	C	300-999	ACT-I		4PI

Abstract—Cross sections per equivalent quantum, in the energy range 0.3–1.0 GeV, have been measured for spallation residuals from ^{51}V , ^{55}Mn , natural Fe, and ^{59}Co targets. Mean cross sections per photon have been deduced in this energy range and the data analysed in terms of charge-dispersion curves and mass-yield distributions. The mean cross sections per photon have also been compared with a semiempirical Rudstam's formula. A satisfactory good agreement has been found with the calculated yields within a factor of two.

Table 4. Yields of radionuclides in units of μb per equivalent quantum. Iron target

Nuclide	0.30	0.40	0.50	0.60	0.75	0.90	1.00
^{24}Na		3.0 ± 0.3	6.0 ± 0.6	8 ± 1	10 ± 1	12 ± 1	13 ± 1
^{27}Mg	3 ± 1	6 ± 1	8 ± 1	10 ± 1	12 ± 1	14 ± 1	15 ± 1
^{28}Mg			0.7 ± 0.2	1.2 ± 0.4	1.8 ± 0.5	2.2 ± 0.5	2.5 ± 0.5
^{29}Al	8 ± 3	18 ± 4	26 ± 4	32 ± 4	40 ± 4	45 ± 4	50 ± 4
^{30}Al	2 ± 1	6 ± 2	10 ± 2	12 ± 2	16 ± 2	18 ± 2	20 ± 2
$^{34}\text{Cl}^m$		8 ± 4	15 ± 4	20 ± 4	27 ± 4	32 ± 4	35 ± 4
^{36}Cl		15 ± 4	25 ± 5	35 ± 7	45 ± 8	55 ± 8	60 ± 8
^{37}Cl		5 ± 2	10 ± 3	13 ± 3	18 ± 3	21 ± 3	23 ± 3
^{41}Ar		2 ± 1	8 ± 2	13 ± 3	20 ± 3	25 ± 3	20 ± 3
^{42}K	20 ± 8	40 ± 10	60 ± 15	70 ± 15	90 ± 15	105 ± 15	115 ± 15
^{43}K		2 ± 1	5 ± 2	15 ± 5	24 ± 5	30 ± 5	34 ± 5
^{44}K	8 ± 4	11 ± 4	13 ± 4	15 ± 4	17 ± 4	19 ± 4	20 ± 4
^{45}K	1.6 ± 0.5	1.9 ± 0.5	2.2 ± 0.5	2.4 ± 0.5	2.7 ± 0.5	2.9 ± 0.5	3.0 ± 0.5
^{46}Ca	3.0 ± 1.0	4.0 ± 1.0	6.0 ± 2.0	7.0 ± 2.0	8.5 ± 2.0	9.4 ± 2.0	10.0 ± 2.0
^{47}Sc	30 ± 8	55 ± 8	80 ± 8	85 ± 8	100 ± 8	100 ± 8	140 ± 8
$^{48}\text{Sc}^m$	140 ± 12	170 ± 12	180 ± 12	204 ± 12	230 ± 12	250 ± 12	260 ± 13
$^{48}\text{Sc}^e$	145 ± 16	170 ± 16	180 ± 16	200 ± 16	230 ± 16	245 ± 16	250 ± 16
^{49}Sc	100 ± 30	100 ± 30	170 ± 35	220 ± 35	260 ± 37	330 ± 38	324 ± 40
^{50}Sc	70 ± 20	80 ± 20	154 ± 30	180 ± 30	210 ± 30	235 ± 30	246 ± 30
^{51}Sc	2 ± 1	2 ± 1	15 ± 3	20 ± 3	28 ± 3	32 ± 3	34 ± 3
^{51}V	490 ± 45	540 ± 45	580 ± 45	620 ± 45	660 ± 45	690 ± 45	710 ± 45
^{52}Cr	24 ± 4	27 ± 4	28 ± 4	30 ± 4	31 ± 4	33 ± 4	34 ± 4
^{54}Cr	142 ± 25	160 ± 25	175 ± 25	187 ± 25	200 ± 25	212 ± 25	220 ± 25
^{55}Cr	2700 ± 130	2900 ± 150	3000 ± 150	3100 ± 150	3200 ± 200	3350 ± 200	3400 ± 200
^{55}Mn	20 ± 5	28 ± 5	35 ± 5	38 ± 5	45 ± 5	47 ± 5	50 ± 5
$^{56}\text{Mn}^m$	410 ± 40	430 ± 40	450 ± 40	460 ± 40	480 ± 40	490 ± 40	500 ± 40
$^{56}\text{Mn}^e$	390 ± 40	415 ± 40	435 ± 40	450 ± 40	475 ± 40	490 ± 40	500 ± 40
^{56}Mn	4670 ± 300	4900 ± 300	5150 ± 300	5300 ± 300	5500 ± 300	5700 ± 300	5800 ± 300

YLDS 24NA TO 54MN

Table 6. Mean cross sections in the energy range 0.3–1 GeV in units of μb

Produced radio-nuclide	Target nucleus				
	Vanadium		Manganese	Iron	Cobalt
	Present work	Bülow <i>et al.</i> [26]			
^{24}Ne	2.0 ± 0.4				
^{27}Na	16 ± 4				
^{28}Na	30 ± 2	18 ± 2	10 ± 1	10 ± 1	7 ± 1
^{28}Mg	22 ± 2	18 ± 3	9 ± 1	10 ± 1	8 ± 1
^{29}Mg	6 ± 1	6 ± 1	2.7 ± 0.5	2.7 ± 0.5	2.2 ± 0.3
^{29}Al	58 ± 7	59 ± 4	29 ± 4	35 ± 4	25 ± 3
^{30}Al	25 ± 4	32 ± 2	11 ± 2	15 ± 2	16 ± 3
$^{34}\text{Cl}^m$	16 ± 2	14 ± 2	30 ± 4	30 ± 4	19 ± 3
^{36}Cl	75 ± 13	96 ± 5	45 ± 8	50 ± 8	37 ± 7
^{37}Cl	37 ± 7	35 ± 1	12 ± 2	19 ± 3	13 ± 2
^{41}Ar	65 ± 6	54 ± 2	35 ± 4	28 ± 3	12 ± 2
^{42}K	280 ± 50	243 ± 11	94 ± 17	80 ± 15	66 ± 12
^{43}K	128 ± 20	128 ± 4	43 ± 7	30 ± 5	28 ± 5
^{44}K	33 ± 12	30 ± 3	11 ± 4	10 ± 4	9.5 ± 4
^{45}K	12 ± 2	8 ± 1	1.0 ± 0.5	1.2 ± 0.5	1.0 ± 0.5
^{46}Ca	12 ± 4	15 ± 1	6.5 ± 2.4	6 ± 2	2.2 ± 0.8
^{47}Sc	104 ± 10	109 ± 6	72 ± 7	77 ± 8	52 ± 6
$^{48}\text{Sc}^m$	260 ± 30	243 ± 14	115 ± 15	100 ± 12	84 ± 10
$^{48}\text{Sc}^e$	230 ± 40	218 ± 13	116 ± 20	90 ± 16	71 ± 13
^{49}Sc	575 ± 100	605 ± 18	260 ± 45	214 ± 35	220 ± 40
^{50}Sc	457 ± 100	540 ± 33	200 ± 45	160 ± 30	127 ± 30
^{51}Sc	165 ± 15	138 ± 8	50 ± 5	30 ± 3	25 ± 3
^{51}V	210 ± 50	307 ± 12	200 ± 50	184 ± 45	100 ± 25
^{52}Cr	20 ± 10		7 ± 3	8 ± 4	5.0 ± 2.5
^{54}Cr	13 ± 5	16 ± 2	40 ± 15	64 ± 25	20 ± 8
^{55}Cr			480 ± 150	570 ± 150	330 ± 150
^{55}Mn				25 ± 5	
$^{56}\text{Mn}^m$				75 ± 40	49 ± 25
$^{56}\text{Mn}^e$				96 ± 40	84 ± 25
^{56}Mn				944 ± 300	584 ± 100
^{56}Fe					1.6 ± 0.8

Table 7. N/Z dispersion parameters of the mean cross sections per photon†

Target nucleus	Mass region	A_m	N/Z_p	Z_p	FWHM	ΔZ	Ref.
^{51}V	42–48	45	1.16	20.8	0.143	1.36	Present work
			1.16	20.8	0.142	1.37	[26]
			1.16	20.9	0.168	1.63	[35]
^{55}Mn	42–48	45	1.16	20.8	0.142	1.37	Present work
^{56}Fe	42–48	45	1.16	20.8	0.140	1.35	Present work
^{59}Co	48–54	51	1.16	23.6	0.126	1.38	Present work
			1.16	20.8	0.141	1.36	Present work
			1.16	23.6	0.124	1.36	Present work

† A_m is the median mass of the mass region under consideration. N/Z_p is the neutron/proton ratio for the most probable nuclear charge Z_p of A_m . FWHM is the full width at half-maximum of the CD curves. ΔZ is the spread in Z as calculated from the FWHM for the two abscissas N/Z_1 and N/Z_2 (see also Refs. [26] and [35]).

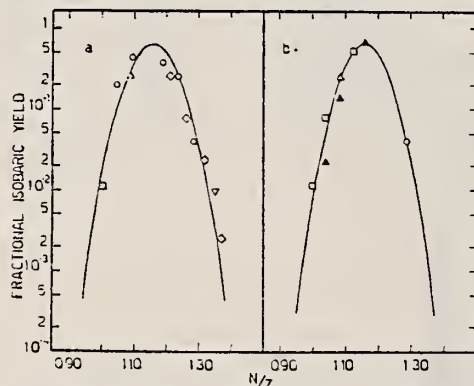


Fig. 2. The same as Fig. 1. Natural Fe target. Graph (a): $42 \leq A \leq 48$; (b): $48 \leq A \leq 54$. The symbols are the same used in Fig. 1 plus Δ , for Mn isotopes.

Fig. 1. Fractional isobaric yield vs the N/Z ratio for $42 \leq A \leq 48$. Mean cross sections per photon in the energy range 0.3–1 GeV. Graph (a): ^{51}V target; (b): ^{55}Mn target. The symbols are: \square , for Cr; \circ , for Sc; Δ , for V; \diamond , for K; ∇ , for Ca isotopes.

Fe
A=54

Fe
A=54

Fe
A=54

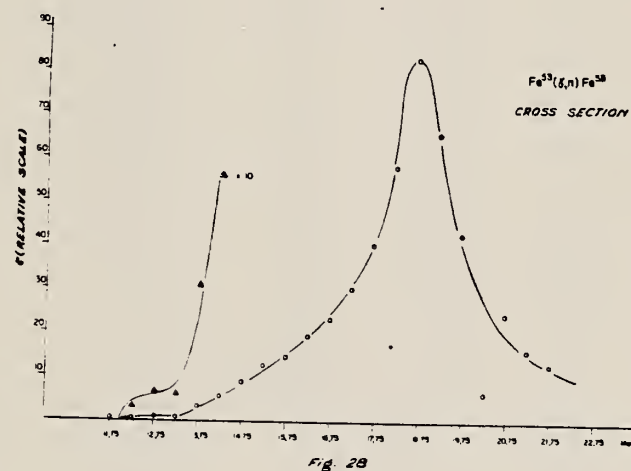
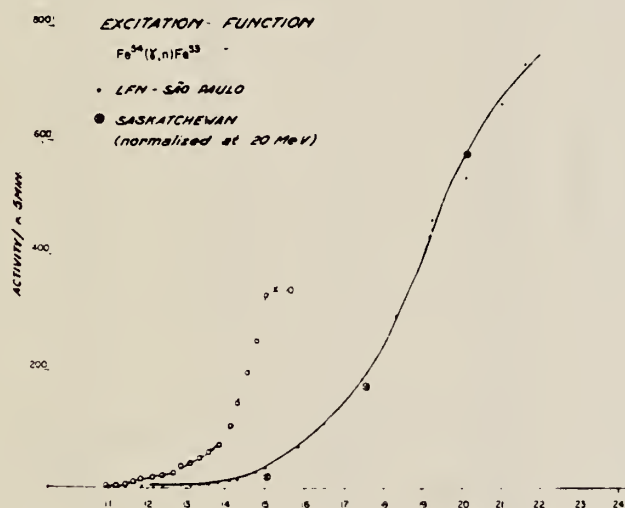
REF. M.D. DeSouze Santos, J. Goldemberg, R.R. Pieroni, E. Silva,
O.A. Borello, S.S. Villaca, J.L. Lopes
Int. Conf. Peaceful Uses of Atomic Energy II (UN, NY), 169 (1955)

ELEM. SYM.	A	Z
Fe	54	26

METHOD

REF. NO.	EGF
55 De 1	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	11-24	C	11-24	ACT-I		4PI



Elem. Sym.	A	Z
Fe	54	26
Ref. No.		
57 Ca 2		EH

Method ³³ MeV electron synchrotron; neutron yield; radioactivity;
Cu ⁶³(γ ,n) reaction (Berman and Brown)

Reaction	E or ΔE	E ₀	Γ	$\int \sigma dE$	J π	Notes
Fe ⁵⁴ (γ ,n)	Bremss. 13-30	19	$\Gamma_{1/2}$: 6.9 MeV	$\int^{31} = 290 \pm 50$ MeV-mb		

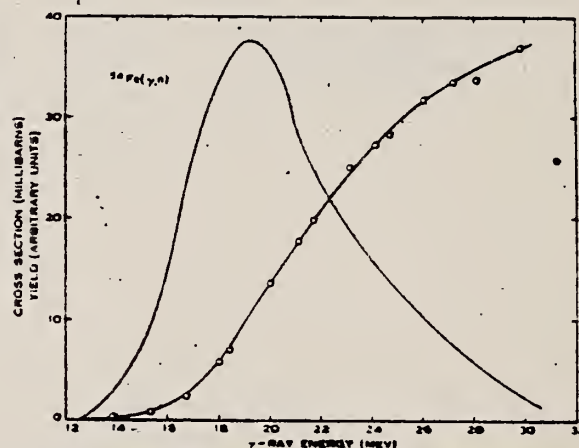


Fig. 4.—The measured yield curve and the derived cross section curve for the reaction ⁵⁴Fe(γ ,n).

TABLE 2
PARAMETERS OF THE MEASURED (γ ,n) CROSS SECTIONS

Reaction	Peak Energy (MeV)	Width at Half Maximum (MeV)	Integrated Cross Section to 31 MeV (MeV mb)
¹³ C (γ ,n)	23	4.2	42 \pm 7
¹⁶ O (γ ,n)	24	3.4	46 \pm 7
⁵⁴ Fe (γ ,n)	19	6.9	290 \pm 50

Elem. Sym.	A	Z
Fe	54	26

Ref. No.	
58 Go 3	EH

FORM NBS-418
(8-1-63)
USCOMM-DC 18856-P63

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

Elem. Sym.	A	Z
Fe	54	26

Ref. No.	62 <u>De</u> 1	JHH
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Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(γ, n)	20.48					$\sigma(\gamma, n) = 30.0 \pm 4.8 \text{ mb}$

REF. W. B. Walters, J. R. Van Hise, W. L. Switzer, J. P. Hummel
Nucl. Phys. A157, 73 (1970)

ELEM. SYM.	A	Z
Fe	54	26

METHOD

REF. NO.	
70 Wa 3	egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,2N	RLY	THR-305	C	150-305	ACT-I		4PI
G,pn	RLY	THR-305	C	150-305	ACT-I		4PI

TABLE 1
Summary of measured yield ratios

Target	Bremsstrahlung energy (MeV)	Measured yield ratio
natural Cr	150	$^{48}\text{Cr}/^{48}\text{V} = 0.043 \pm 0.002$
	250	0.047 ± 0.009
	305	0.042 ± 0.002
enriched ^{52}Cr	250	0.025 ± 0.005
natural Fe	250	$^{52}\text{Fe}/^{52}\text{Mn} = 0.037 \pm 0.003$
enriched ^{56}Fe	250	0.024 ± 0.005
		$^{52}\text{Mn}/(^{52}\text{Mn} + ^{25}\text{Mn}) = 0.47 \pm 0.02$
natural Y	150	$^{87}\text{Y}/^{87}\text{mSr} = 12.9 \pm 1.6$
natural Mo	150	$^{90}\text{Mo}/^{90}\text{Nb} = 0.41 \pm 0.05$
	280	0.49 ± 0.05

TABLE 2
Summary of experimental and theoretical ratios of (γ , 2n) to (γ , pn) yields

Target isotope	Bremsstrahlung energy (MeV)	Experimental (γ , 2n)/(γ , pn) yield ratio	Calculated (γ , 2n)/(γ , pn) yield ratio
^{50}Cr	250	0.095 ± 0.025	0.14
^{54}Fe	250	0.10 ± 0.03	0.07
^{89}Y	150	7.4 ± 1.0	6.7
^{92}Mo	150	0.41 ± 0.05	0.15
	280	0.49 ± 0.05	0.16

REF.

A. S. Litvinenko, N. G. Shevchenko, A. Yu. Buki, P. L. Kondrat'ev,
G. A. Savitskii, A. A. Khomich, V. M. Khvastunov, I. I. Chkalov
Ukr. Fiz. Zhur. 17, 1197 (1972)

ELEM. SYM.	A	Z
Fe	54	26
REF. NO.		hmg
72 L1 3		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FME	1, 5	D	150, 225	MAG-D		DST

B(EL) LEV 1.17.3.75

Таблица 1

Параметры фермиевского распределения плотности заряда
(с—радиус полуспада плотности, t—диффузионность ядра)

Ядро	с, ф	t, ф
Fe ⁵⁴	4.012 ± 0.007	2.346 ± 0.011
Fe ⁵⁶	3.971 ± 0.013	2.608 ± 0.020
Fe ⁵⁸	4.027 ± 0.019	2.530 ± 0.031
Ni ⁵⁸	4.149 ± 0.011	2.506 ± 0.016

¹ Институт ядерных исследований АН СССР.

Таблица 2

Ядро	E _λ , Мэв	J ^π	Данные настоящей работы	Данные других работ		Литература
			B(Eλ) ↑, э.л.ф.2λ	B(Eλ) ↑, э.л.ф.2λ	Тип эксперимента и метод определения	
Fe ⁵⁴	1.4	2 ⁺	531.9 ± 32.4	533	(ee'), борновское приближение	[6]
	4.85	3 ⁻	4563 ± 410	4390		
Fe ⁵⁶	0.85	2 ⁺	678.1 ± 47.5	720	(ee'), борновское приближение искаженные волны борновское приближение кулоновское возбуждение	[7] [8]
				1250 ± 270		
				1240 900 ± 100		
Fe ⁵⁸	0.81	2 ⁺	943.2 ± 79			
	3.86	3 ⁻	13880 ± 1260			
Ni ⁵⁸	1.17	2 ⁺	618.6 ± 42.1	877 ± 11	(ee'), искаженные волны	[9]
	3.75	3 ⁻	14359 ± 962	20100 ± 540		

METHOD

REF. NO.

73 Ho 4

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1- 5	D	209	MAG-D		DST

1.41, 2.54, 4.78

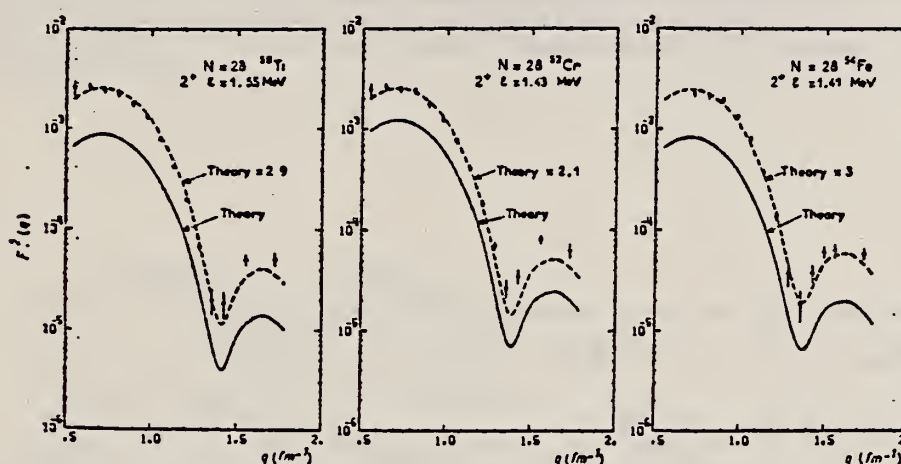


Fig. 5a. Squared inelastic form factor for 2^+ states of the $N = 28$ isotones.

TABLE 4
Inelastic cross sections for $E_x = 209$ MeV on ^{54}Fe

		θ (deg.)	$(2^+)\epsilon = 1.41$ MeV $d\sigma/d\Omega$ (mb/sr)	$(3^-)\epsilon = 4.78$ MeV $d\sigma/d\Omega$ (mb/sr)	$(4^+)\epsilon = 2.54$ MeV $d\sigma/d\Omega$ (mb/sr)
(4^+) 5.09 4.95 4.28 4.05 3.84	(3^-) 4.79 4.70 4.66 4.58 (2^+)	35		$0.168 \text{ E}-2 \pm 0.940 \text{ E}-3$	
		40	$0.119 \text{ E}-1 \pm 0.100 \text{ E}-2$	$0.156 \text{ E}-2 \pm 0.420 \text{ E}-3$	
		45	$0.683 \text{ E}-2 \pm 0.430 \text{ E}-3$	$0.117 \text{ E}-2 \pm 0.160 \text{ E}-3$	
		50	$0.401 \text{ E}-2 \pm 0.210 \text{ E}-3$	$0.831 \text{ E}-3 \pm 0.670 \text{ E}-4$	$0.191 \text{ E}-3 \pm 0.320 \text{ E}-4$
		55	$0.183 \text{ E}-2 \pm 0.100 \text{ E}-3$	$0.571 \text{ E}-3 \pm 0.400 \text{ E}-4$	$0.215 \text{ E}-3 \pm 0.150 \text{ E}-4$
(4^+) 3.34 3.30 3.16 2.96 2.95	(4^+) (2^+) (2^+) (6^+)	60	$0.766 \text{ E}-3 \pm 0.410 \text{ E}-4$	$0.412 \text{ E}-3 \pm 0.300 \text{ E}-4$	$0.174 \text{ E}-3 \pm 0.100 \text{ E}-4$
		65	$0.256 \text{ E}-3 \pm 0.170 \text{ E}-4$	$0.270 \text{ E}-3 \pm 0.180 \text{ E}-4$	$0.140 \text{ E}-3 \pm 0.900 \text{ E}-5$
		70	$0.687 \text{ E}-4 \pm 0.740 \text{ E}-5$	$0.157 \text{ E}-3 \pm 0.110 \text{ E}-4$	$0.106 \text{ E}-3 \pm 0.700 \text{ E}-5$
		75	$0.138 \text{ E}-4 \pm 0.360 \text{ E}-5$	$0.951 \text{ E}-4 \pm 0.820 \text{ E}-5$	$0.764 \text{ E}-4 \pm 0.550 \text{ E}-5$
		80	$0.509 \text{ E}-5 \pm 0.174 \text{ E}-5$	$0.453 \text{ E}-4 \pm 0.380 \text{ E}-5$	$0.523 \text{ E}-4 \pm 0.320 \text{ E}-5$
(0^+) 2.56 (4^+) 2.54		85	$0.781 \text{ E}-5 \pm 0.142 \text{ E}-5$	$0.151 \text{ E}-4 \pm 0.210 \text{ E}-5$	$0.311 \text{ E}-4 \pm 0.210 \text{ E}-5$
		90	$0.974 \text{ E}-5 \pm 0.120 \text{ E}-5$	$0.752 \text{ E}-5 \pm 0.126 \text{ E}-5$	$0.220 \text{ E}-4 \pm 0.140 \text{ E}-5$
		95	$0.781 \text{ E}-5 \pm 0.113 \text{ E}-5$	$0.184 \text{ E}-5 \pm 0.960 \text{ E}-6$	$0.116 \text{ E}-4 \pm 0.100 \text{ E}-5$
		110	$0.342 \text{ E}-5 \pm 0.390 \text{ E}-6$	$0.174 \text{ E}-6 \pm 0.107 \text{ E}-6$	$0.194 \text{ E}-5 \pm 0.230 \text{ E}-6$
(2^+) 1.41					

Energy level diagram given by ref. ²⁴). Levels excited in our experiment are shown with solid lines, dashed lines correspond to other levels. The experimental values are normalized on our elastic cross sections considered as reference values.

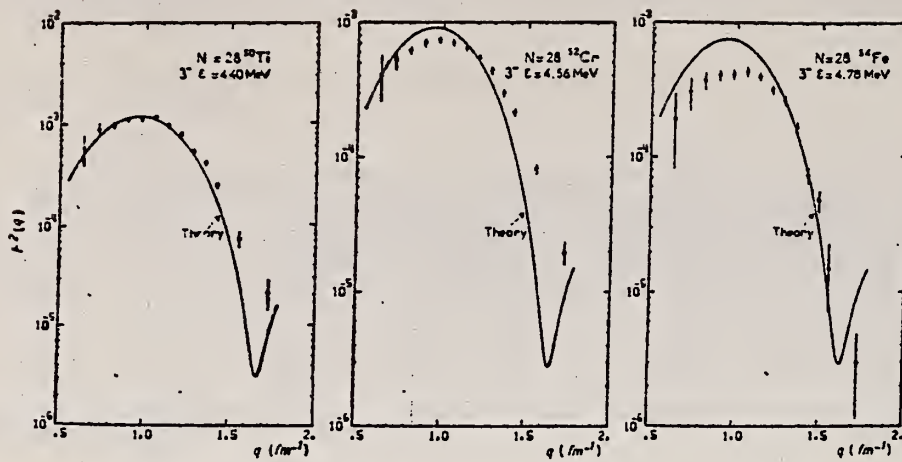


Fig. 6a. Squared inelastic form factor for 3^- states of the $N = 28$ isotones.

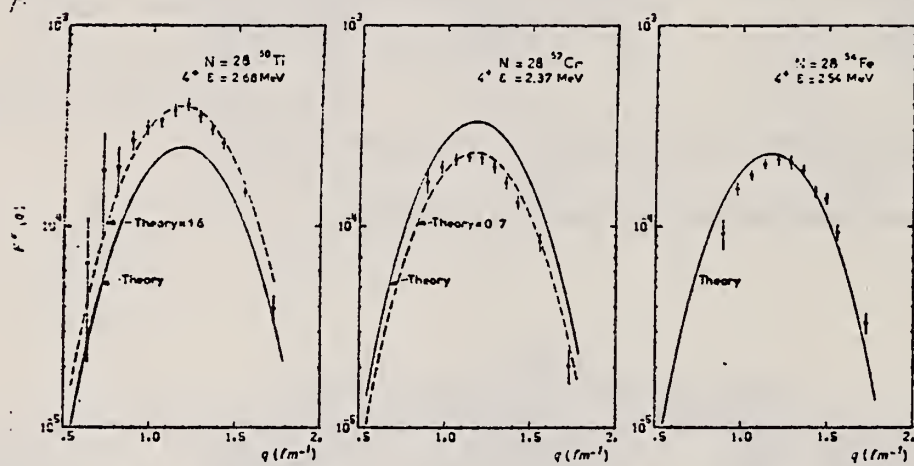


Fig. 7a. Squared inelastic form factor for 4^+ states of the $N = 28$ isotones.

REF.

I. A. Grishaev, N. I. Lapin, G. D. Pugachev
 Yad. Fiz. 24, 335 (1976)
 Sov. J. Nucl. Phys. 24, 175 (1976)

ELEM. SYM.	A	Z
Fe	54	26

METHOD

REF. NO.

76 Gr 3

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,PI+	SPC	150-500	C	500	EMU-I		DST
G,PI-	SPC	150-500	C	500	EMU-I		DST

The energy spectra of charged photopions from ^{54}Fe , ^{56}Fe , and ^{58}Ni targets irradiated with bremsstrahlung of maximum energy 500 MeV have been measured at photopion-emission angles of 30, 60, 90, 120, and 150° in the lab system over the kinetic-energy range from 15 to 80 MeV. Isotope effects are found in the π^- yields at 30, 60, and 90°. At all angles and energies, the π^+ yields are the same for all three targets within the experimental error.

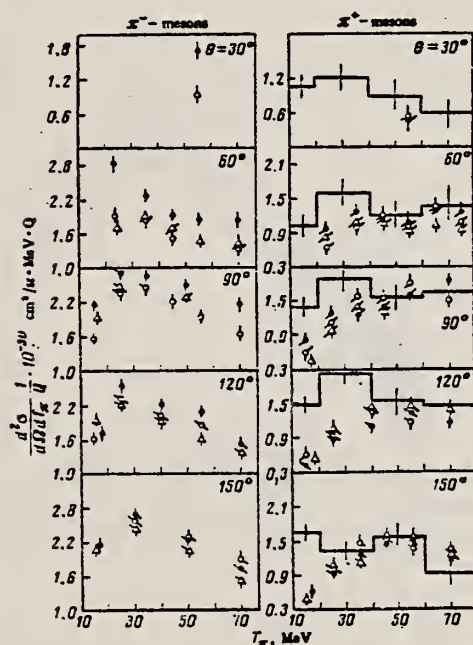


FIG. 1. Energy spectra of charged photopions from ^{54}Fe , ^{56}Fe , and ^{58}Ni targets (open circles, black circles, and triangles, respectively) at $E_0=500$ MeV. The error bars represent statistical errors. The histograms on the π^+ -meson plots represent the results of cascade-model calculations for ^{56}Fe .

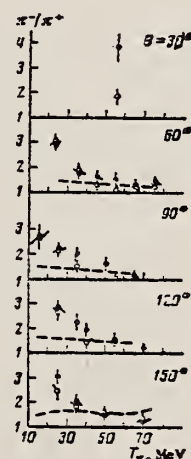


FIG. 2. The π^-/π^+ yield ratios for ^{56}Fe (black circles) and ^{54}Fe (open circles) targets vs photopion kinetic energy. The dashed curves were calculated with Eq. (4).

REF.

H. Lancman, R. J. Sparks, C. Van der Leun
Nucl. Phys. A257, 29 (1976)

ELEM. SYM.	A	Z
Fe	54	26
REF. NO.		
76 La 1		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	6	D	6	SCD-D		DST

6=6.13

Abstract: The narrow 6.13 MeV γ -line from the $^{19}\text{F}(p, \alpha\gamma)^{16}\text{O}$ reaction was used to excite a level of ^{54}Fe . Resonance fluorescence spectra, angular distributions and the temperature dependence of the intensity of the scattered photons were measured. In addition to the decay scheme of the ^{54}Fe level, its following characteristics were determined: $E_x = 6129.0 \pm 0.2$ keV, $J = 1$, $T = 27 \pm 4$ meV, $\Gamma_0/\Gamma = 0.93 \pm 0.01$. The separation energy between the incident line and the absorption line was found to be 17.0 ± 1.0 eV.

METHOD

REF. NO.	hg
76 Ve 3	

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	RLX	13-27	C	13-27	SCI-D		UKN

The pre-equilibrium nuclear decay, with which the existence of the intermediate structures seems to be connected, leads to predominate emission of high-energy neutrons.^[1] There are therefore grounds for expecting the structure and the cross section of the (γ, n) reaction due to the emission of the high-energy component of the neutron spectrum to become manifest most distinctly.

We have investigated the yield of the (γ, n) reaction for the nucleus Fe^{54} at different values of the minimum energy of the registered neutrons, and also

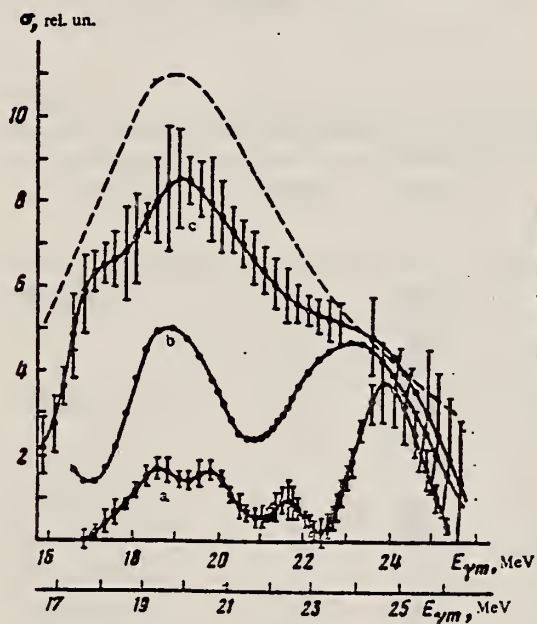


FIG. 1. Cross section of the reaction $\text{Fe}^{54}(\gamma, n)\text{Fe}^{53}$. The threshold for the neutron registration was: a) 3.7 MeV, b) 3.2 MeV, c) 0.9 MeV. Dashed curve—cross section of the reaction $\text{Fe}^{54}(\gamma, n)$ from [4].

(over)

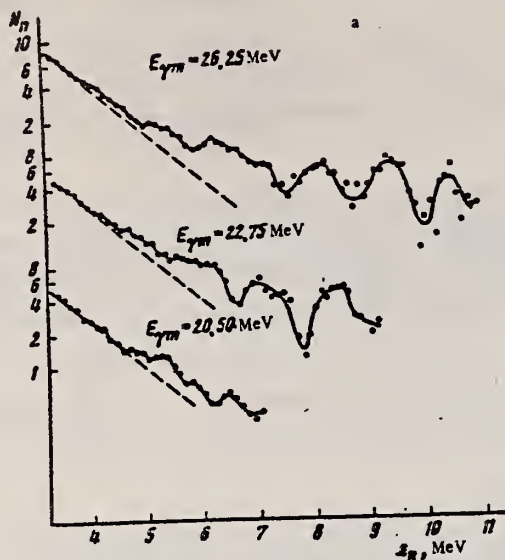
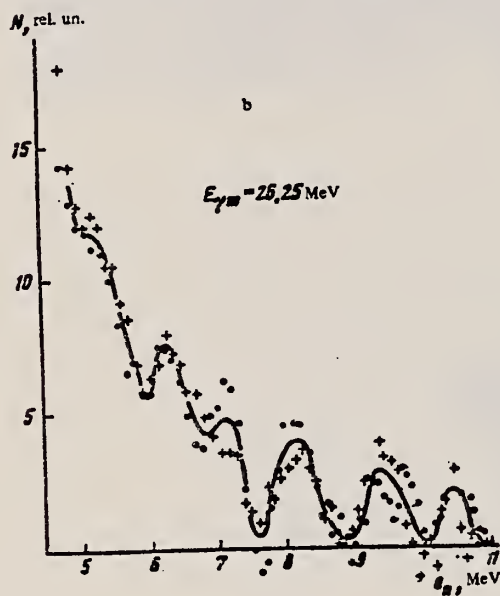


FIG. 2. Energy spectra of photoneutrons from the $\text{Fe}^{54}(\gamma, n)$ reaction.



Position of the peak in the energy spectrum of the neutrons ϵ_m , MeV			Position of Fe^{54} resonance E_R , MeV	Position of Fe^{54} levels $E = E_R - \bar{\epsilon}_m - \epsilon_{n.}$, MeV		
$E_{\gamma m} = 20.5 \text{ MeV}$	$E_{\gamma m} = 22.75 \text{ MeV}$	$E_{\gamma m} = 26.25 \text{ MeV}$				
4.1	4.1	4.1	19.5	-	1.9	-
4.7	4.7	4.6	19.5	-	-	1.2
5.3	5.1	5.2	19.5	0.7	-	-
6.4	6.1	6.2	20.7	0.9	-	-
-	7.0	7.2	22.5	-	1.8	-
-	8.4	8.1	22.5	0.7	-	-
-	-	9.5	24.8	-	1.7	-
-	-	10.5	24.8	0.8	-	-
Average				0.8	1.8	1.2

$\epsilon_{n.}$ - is the neutron binding energy 13.6 MeV.

METHOD					REF. NO.	
					77 Hi 5	hmg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,N	ABI	13-30 (13.4)	C	18-30	ACT-I	4PI

THICK BREMS TARGET

The integral experiment for a sensitivity check of photonuclear cross section data of C, Mn, Fe, In and Au was performed by using the bremsstrahlung produced in a thick iron target by 18, 22, 26 and 30 MeV electrons from a linear accelerator. The cross section data measured by the activation method showed better results for all incident electron energies than those by the photoneutron method, because the latter include the competing (γ, np) reaction above its threshold energy. It is necessary to obtain the cross section data of (γ, n), (γ, np), ($\gamma, 2n$), ($\gamma, p2n$) reactions etc., separately by the activation method.

The effective energy range and effective cross section in the giant resonance region were determined for C, Mn, Fe and Au. By using these quantities, the gross structure of the bremsstrahlung spectrum was obtained in good agreement with the theoretical calculation.

TABLE 3

Ratio of measured and calculated saturated activities at 9° , $R_i = A_i^{\text{exp}}/A_i^{\text{cal}}$.

Reaction	Reference	Detector	Electron energy				Threshold energy of competing (γ, np) reaction (MeV)
			18 MeV	22 MeV	26 MeV	30 MeV	
$^{12}\text{C}(\gamma, n)^{11}\text{C}$	6	ACT ^a	-	1.205	1.09	0.824	27.4
	7	BF3 ^b	-	0.757	0.931	-	
	8	BF3	-	1.492	1.189	0.914	
	9	BF3	-	1.418	1.159	-	
$^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$	10	BF3	0.575	0.810	0.598	-	17.8
	11		0.595	0.875	0.654	0.609	
$^{54}\text{Fe}(\gamma, n)^{53}\text{Fe}$	12	ACT	0.542	0.783	0.722	1.12	20.9
$^{115}\text{In}(\gamma, n)^{114\text{m}}\text{In}$	13	BF3	0.448	0.511	-	-	15.9
	14	BF3	0.603	0.672	0.586	1.00	
$^{115}\text{In}(\gamma, \gamma)^{115\text{m}}\text{In}$	15	ACT	0.829	1.00	0.852	0.995	
$^{197}\text{Au}(\gamma, n)^{196}\text{Au}$	16	BF3	0.743	0.553	0.529	-	13.7
	17	BF3	0.842	0.628	0.608	0.476	

^a ACT: measurement of radioactivity of the target.

^b BF3: BF₃ neutron counter with moderator.

TABLE 4

Effective cross section and effective energy range.

Reaction	Effective energy range (MeV)	Effective cross section (mb)			Average
		22 MeV	26 MeV	30 MeV	
$^{12}\text{C}(\gamma, n)^{11}\text{C}$	20.5–24.5	—	5.98	5.28	5.63 ± 0.35
$^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$	15.0–20.5	—	56.2	52.7	54.5 ± 1.7
$^{54}\text{Fe}(\gamma, n)^{53}\text{Fe}$	17.0–24.0	—	33.6	47.9	40.8 ± 7.2
$^{197}\text{Au}(\gamma, n)^{196}\text{Au}$	12.5–15.0	553.5	532.5	415.0	500 ± 85

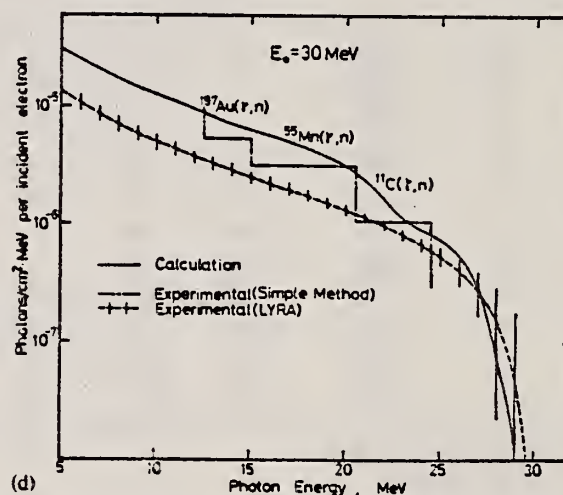
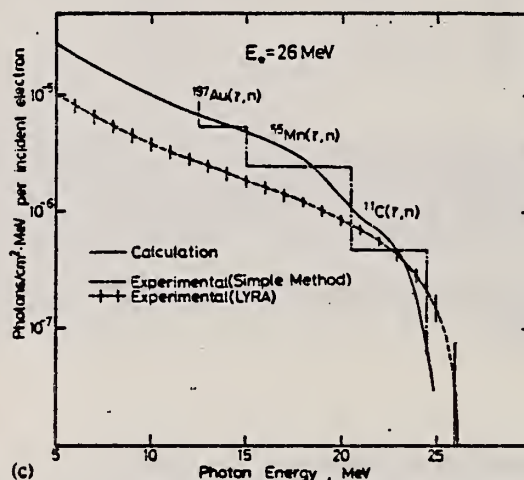
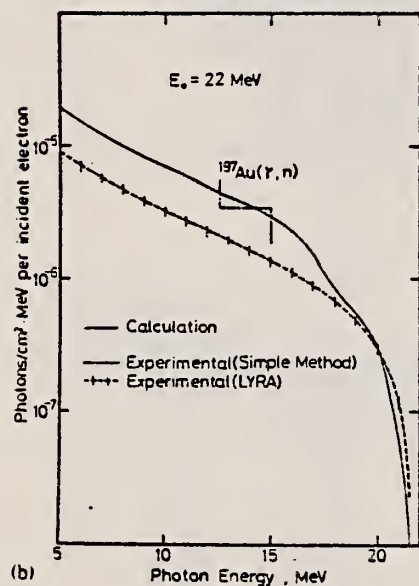
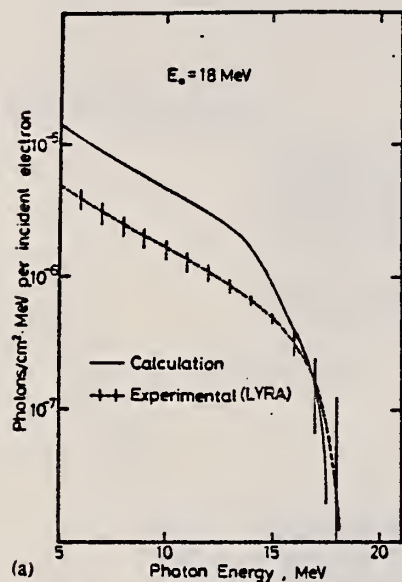


Fig. 3. Comparison of experimental and calculated bremsstrahlung spectra emitted from an iron target in the 9° direction by (a) 18 MeV electrons, (b) 22 MeV electrons, (c) 26 MeV electrons, (d) 30 MeV electrons.

METHOD

REF. NO.	
77 Ra 3	efg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	SPC	16-26	C	15-26	SCI-D		UKN

FAST NEUTS

TABLE 2

Relationship between the structure in the energy spectra and the structure in the photoneutron cross section for ^{54}Fe

Position of peak in neutron energy spectrum ϵ (MeV)					Position of resonance ^{54}Fe E_R (MeV)	Position of level $^{53}\text{Fe}^*)$ $E = E_R - \bar{\epsilon} - E_{\text{re}}^b)$	
$E_{\gamma, \text{max}}$ (MeV)							
18.75	19.75	20.50	22.75	26.25			
4.7	4.8	4.7	4.7	4.6	18.4	0	
(4.1)	(4.1)	4.1	4.1	4.1	19.5 (18.4)	(0.6)	1.7
	5.4	5.3	5.1	5.2	19.5	0.65	
		6.4	6.1	6.2	20.7	0.8	
			7.1	7.0	22.5		1.8
			8.3	8.0	22.5	0.65	
				9.5	24.8		1.5
				10.4	24.8	0.6	
						<i>mean value:</i>	
						0	0.68 1.67
						<i>spectroscopic data:</i>	
						0	0.74 1.70

^{a)} A nuclear recoil correction has been introduced.

^{b)} $\bar{\epsilon}$ is ϵ averaged by $E_{\gamma, \text{max}}$.

ELEM. SYM.	A	Z
Fe	54	26
REF. NO.		hg
78 Ma 10		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,2N	ABY	24-68	C	30-68	ACT - I		4PI
G,PN	ABY	21-68	C	30-68	ACT - I		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

(G,PN) TO MN-52G

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

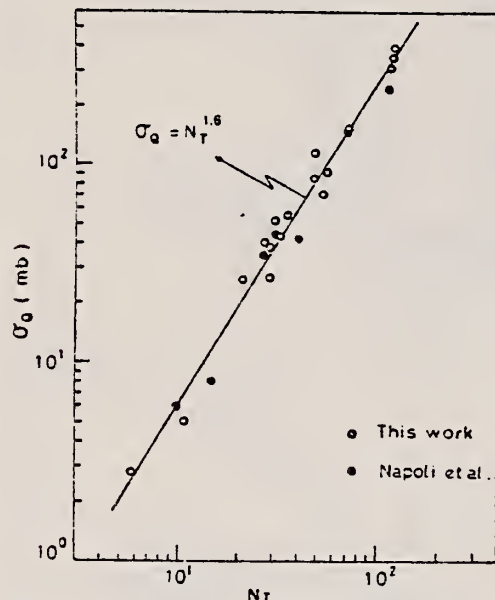


Fig. 2. Yield per equivalent quanta versus target neutron number.

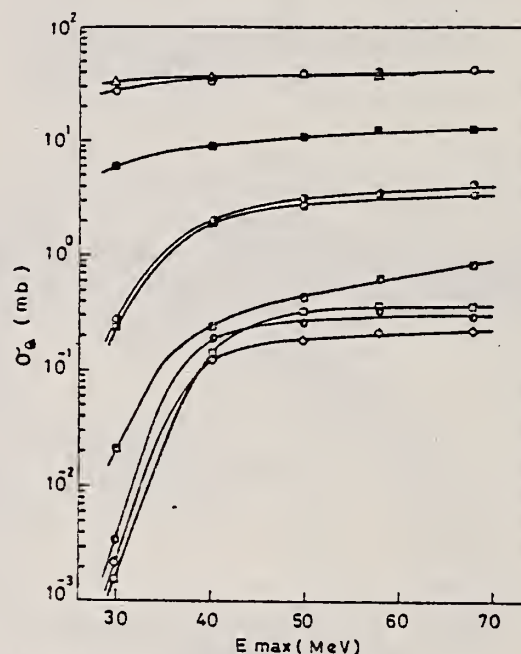


Fig. 5. Activation yield curves for the reactions on Cr, Mn and Fe.
 \circ $^{52}\text{Cr}(\gamma, n)^{51}\text{Cr}$, \bullet $^{50}\text{Cr}(\gamma, pn)^{48}\text{V}$, \oplus $^{50}\text{Cr}(\gamma, 2n)^{48}\text{Cr}$,
 \triangle $^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$, \blacksquare $^{57}\text{Fe}(\gamma, p)^{56}\text{Mn}$, \boxtimes $^{54}\text{Fe}(\gamma, pn)^{52}\text{Mn}$,
 \blacksquare $^{56}\text{Fe}(\gamma, pn)^{54}\text{Mn}$, \square $^{56}\text{Fe}(\gamma, xn)^{51}\text{Cr}$, \diamond $^{54}\text{Fe}(\gamma, 2n)^{52}\text{Fe}$.

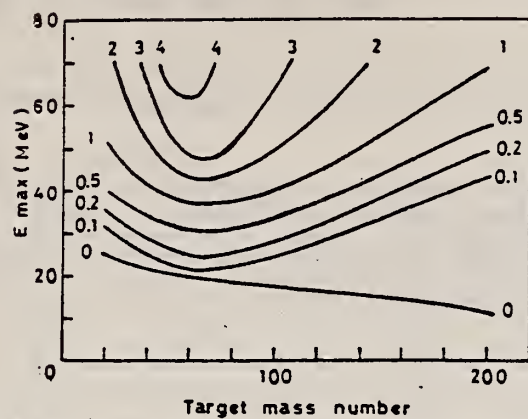


Fig. 11. Yields of the (γ, pn) reactions as a function of bremsstrahlung maximum energy, and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

REF. J.W. Norbury, M.N. Thompson, K. Shoda, H. Tsubota
Aust. J. Phys. 31, 471 (1978)

ELEM. SYM.	A	Z
Fe	54	26
REF. NO.		hg
78 No 2		

METHOD				REF. NO.		hg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G,N	ABX	13-25	C	12-18	ACT-I	4PI

Abstract

A high resolution measurement of the $^{54}\text{Fe}(\gamma, n)$ cross section is reported. This and a previously measured $^{54}\text{Fe}(\gamma, p)$ cross section are discussed in terms of the isospin splitting of the E1 giant dipole.

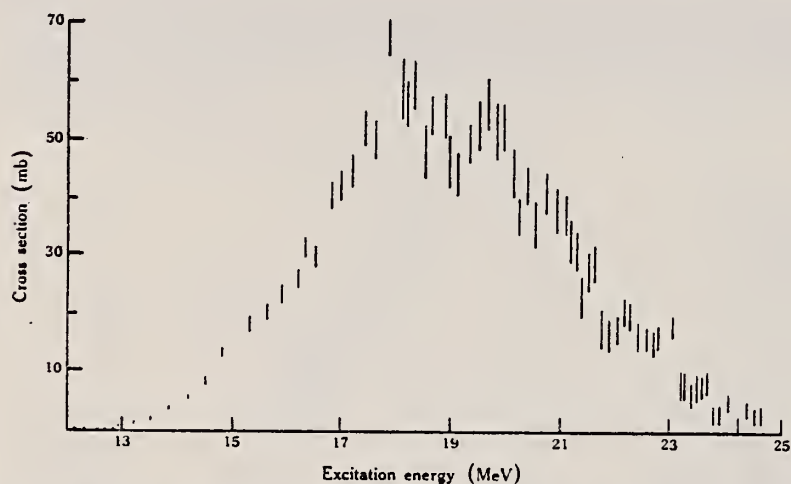


Fig. 1. $^{54}\text{Fe}(\gamma, n)^{53}\text{Fe}$ cross section obtained from the present high resolution measurement.

REF. R.A. Lindgren, J.B. Flanz, R.S. Hicks, B. Parker, G.A. Peterson,
R.D. Lawson, W. Teeters, C.F. Williamson, S. Kowalski, X.K. Maruyama
Phys. Rev. Lett. 46, 706 (1981)

ELEM. SYM.	A	Z
Fe	54	26
REF. NO.		
81 Li 2		hg

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	13	D	131-338	MAG-D		DST
		(13.263)					

Inelastic electron scattering is used to identify $M8$ transitions and assign $J^\pi = 8^-$ to states at $E_x = 8.314, 8.949, 9.974, 10.677$, and 13.263 MeV excitations. Shell-model calculations within the model space $[g_{9/2} \otimes (f_{7/2}^{-3})]_8^-$ suggest that the four lowest states are $T = 1$ and the strongest excitation, to the state at 13.263 MeV, is $T = 2$.

5 M8 STATES 8-14 MEV

PACS numbers: 25.30.Cq, 27.40.+z

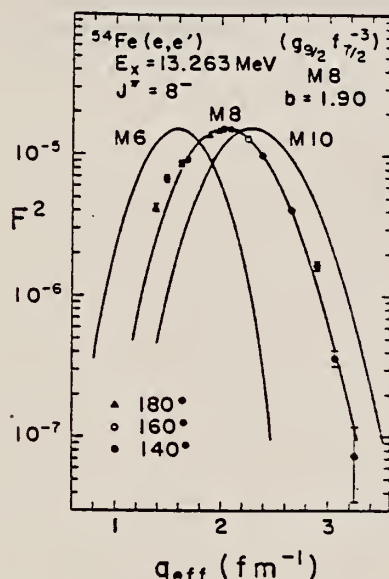


FIG. 2. The form factor squared, F^2 , is plotted vs the effective momentum transfer, q_{eff} . Here, $F^2 = \eta(d\sigma/d\Omega)_{exp}/Z^2\sigma_M(\frac{1}{2} + \tan^2 \frac{1}{2}\theta)$, where η is the usual recoil factor, $(d\sigma/d\Omega)_{exp}$ is the measured cross section at angle θ , and σ_M is the Mott scattering cross section. In plane-wave Born approximation, $q_{eff} = q(1 + \frac{2}{3}Z\alpha\hbar c/E_0 R)$, where $R = \frac{5}{3}\langle r^2 \rangle^{1/2}$ and $\langle r^2 \rangle^{1/2} = 3.681$ fm, the rms radius of the ground-state charge distribution of ^{54}Fe (Ref. 10).

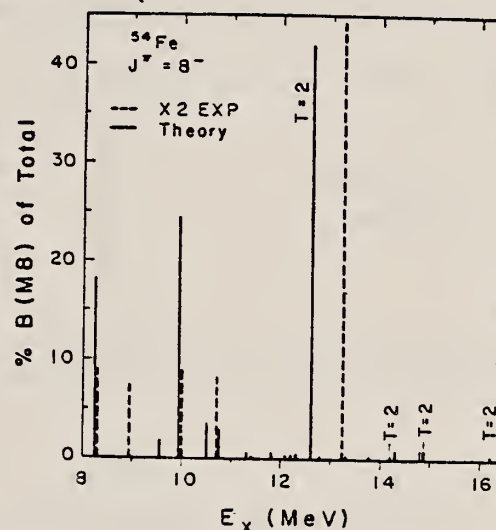


FIG. 3. Experimentally determined and calculated $M8$ transition strength plotted as a fraction of the total $M8$ strength. The total $M8$ strength or $M8$ sum rule is obtained by taking Eq. (3) with $(\alpha = 1, \beta = 0)$ and with $(\alpha = 0, \beta = 1)$ and adding both to Eq. (4) with $\gamma = 1$. The result is $F^2 = \frac{1}{8}(7M_1^2 + 2M_0M_1 + 7M_0^2)$. The $T = 2$ $M8$ sum rule is obtained from Eq. (4) with $\gamma = 1$.

REF. G. Eulenberg, D.I. Sober, W. Steffen, H.-D. Gräf, G. Kuchler,
A. Richter, E. Spamer, B.C. Metsch, W. Knüpfer
Phys. Lett. 116B, 113 (1982)

ELEM. SYM.	A	Z
Fe	54	26
REF. NO.		
82 Eu 1		egf

METHOD					REF. NO.	
					82 Eu 1	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
E,e/	ABX	8-12	D	30-58	MAG-D	

M1 STRENGTH

Following the recent discovery of a very strong magnetic dipole transition in ^{48}Ca to a state at 10.23 MeV in high-resolution inelastic electron scattering, results of a detailed search for M1 strength in the other $N = 28$ Isotones ^{50}Ti , ^{52}Cr and ^{54}Fe are described. The M1 strength found in the investigated region of excitation energy $E_x \approx 7-12$ MeV is very fragmented and considerably quenched in comparison to predictions of shell model calculations in a model space that includes up to $2p-2h$ excitations.

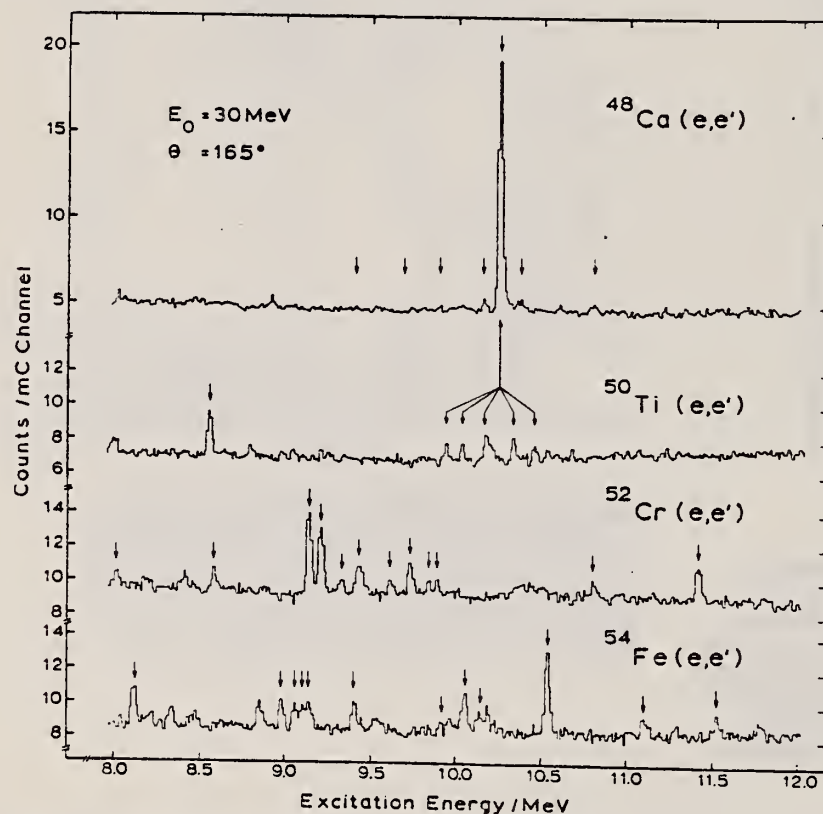


Fig. 1. High-resolution inelastic electron scattering spectra of the $N = 28$ isotones all measured at $E_0 = 30$ MeV and at $\theta = 165^\circ$. The strongest magnetic dipole transitions are indicated by arrows.

(OVER)

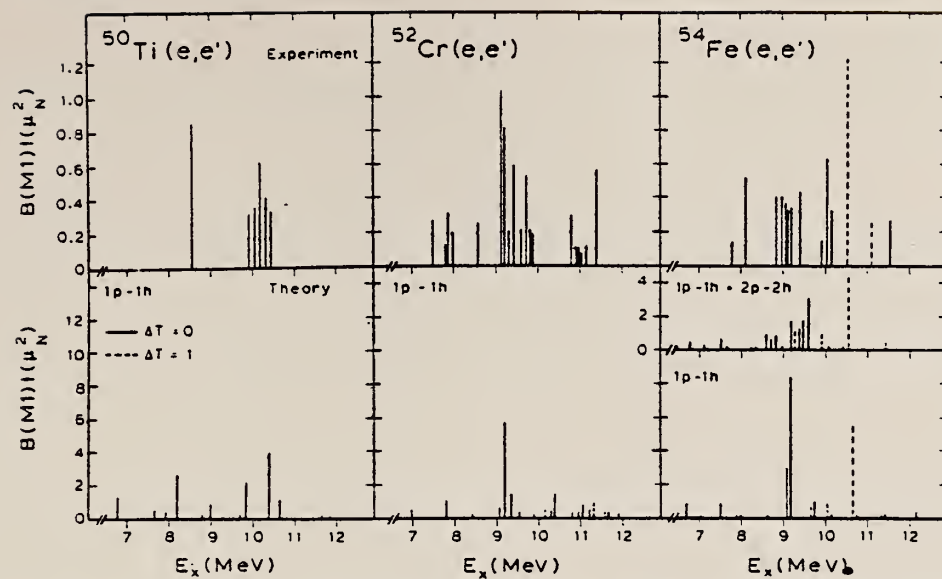


Fig. 3. Comparison of experimental and calculated M1 strength distributions for ^{50}Ti , ^{52}Cr and ^{54}Fe . Note the scale difference. For details, see the main text.

Fe
A=56

Fe
A=56

Fe
A=56

Method 22 MeV betatron; neutron counters

Ref. No.	EH
58 To 1	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Fe}^{56}(\gamma, n)$	Bremss. 22					$E_{th} = 11.34 \pm 0.10$

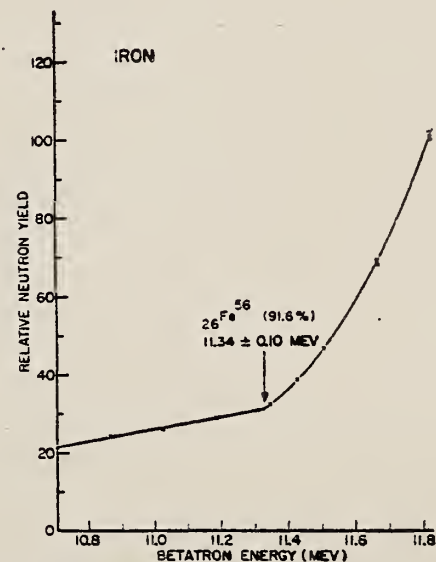


FIG. 3. Photoneutron yield from iron in the betatron-energy range from 10.7 to 11.8 Mev.

Fe

56

26

METHOD

Betatron; neutron threshold; ion chamber

REF. NO.

60 Ge 3

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, N	NØX	THR	C	THR	BF3-I		4 PI

THRESHOLD

TABLE I. Summary and comparison of neutron separation energies inferred from present threshold measurements with values predicted from mass data and reaction energies. All energies are expressed in the center-of-mass system in Mev.

Reaction	No. runs	Present results	Other results	Method	Reference
$Fe^{56}(\gamma, n)Fe^{55}$	1	11.25 ± 0.06	11.159 ± 0.028 11.34 ± 0.10	mass data threshold	j k

j K. S. Quisenberry, T. T. Scolman, and A. O. Nier, Phys. Rev. 104, 461 (1956).
k See reference 2.

Elem. Sym.	A	Z
Fe	56	26

Ref. No.	
61 Ke 2	JHH

FORM NBS-418
(8-1-63)
USCOMM-DC 18556-P63

U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

METHOD				REF. NO.	
100 MeV synchrotron				64 Co 3	
				JDM	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G, N	AB	THR-80	C	10-80	4PI

TABLE

ELEMENT	Yield (36 MeV) $\left(\frac{n \cdot cm^2}{mol \cdot MeV} \times 10^5\right)$	Σ_0^{30}	Σ_0^{80}	$\Sigma_0^{30} / \Sigma_0^{80}$	σ_{-1} (mb)
²⁴ Cr	83	1.21	2.1	0.58	62
²⁵ Mn	108	1.52	2.33	0.65	76
²⁶ Fe	68	0.88	1.46	0.60	50
²⁷ Co	89	1.08	1.82	0.59	64
²⁸ Ni	44	0.55	1.07	0.51	34
²⁹ Cu	95	1.06	1.99	0.53	72
³⁰ Zn	88	0.94	1.68	0.56	66
³¹ Ga	130	1.29	2.18	0.59	94
³² Ge	139	1.35	2.29	0.59	101
³³ As	137	1.22	2.18	0.56	100

$\Sigma_0^b = \frac{A}{60 NZ} \int_a^b \sigma(E) dE$ is the integrated cross section measured in units of the classical dipole $60 NZ/A$ mb. MeV.

REF.

B.L. Berman, G.S. Sidhu, and C.D. Bowman
Phys. Rev. Letters 17, 761 (1966)

ELEM. SYM.

A

Z

Fe

56

26

METHOD

Linac

REF. NO.

66 Be 4

JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G _n N	ABX	11	C	13	TOF-D		135

The absolute cross section might contain systematic errors of up to 50%.

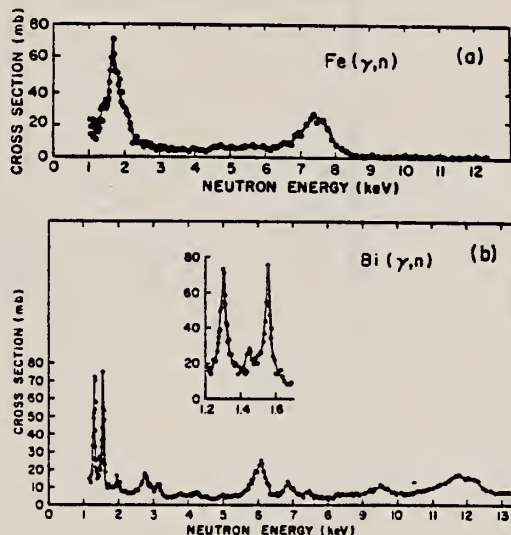


FIG. 2. Absolute cross section for threshold photo-neutrons from iron and bismuth as a function of laboratory neutron energy [$\sigma = 4\pi(d\sigma/d\Omega)|_{135^\circ}$].

(OVER)

Table I. Experimental parameters.

Sample		Target		Bremsstrahlung conversion efficiency		Average beam current		Beam burst width		Run time
Neutron sample	thickness (in.)	$E_{thr}(\gamma, n)$ (MeV)	Bremsstrahlung target	thickness (in.)	E_e (MeV)	10^{-3} photon/electron sr eV	Ω_γ (sr)	μA	($\mu sec/channel$)	(h)
Fe	1.017	11.21 ^a	Al	1.015	12.5	1.57	0.025	36.8	0.125	500 4
Bi	0.502	7.43	Ag	0.249	11.0	4.64	0.133	6.4	0.0625	40-100 34

^a Fe⁵⁶ (isotopic abundance 91.7%).

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	12,13	C	12,13	TOF-D	0-1	135
		(11.6,12.7)		(11.6,12.7)		(0-70 keV)	

Spin of the two major resonances is 1^- .

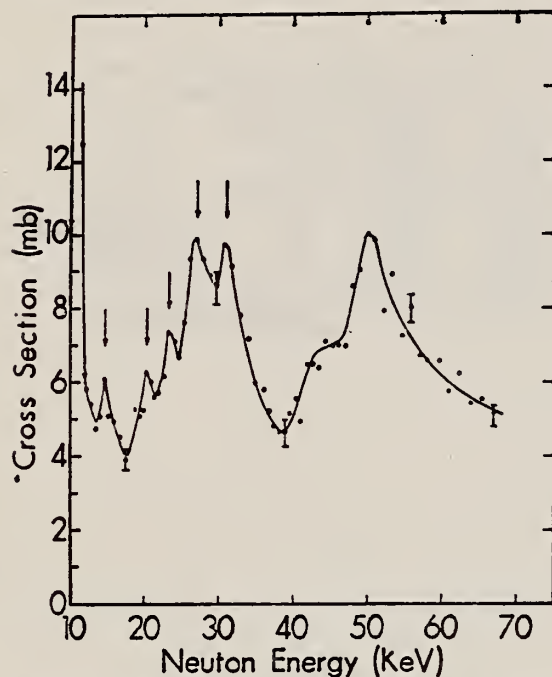


FIG. 6. Absolute photoneutron cross section $\sigma = 4\pi(d\sigma/d\Omega)_{135}$. The counting statistics for this experiment are shown for a few points by the error bars. The absolute cross-section scale is uncertain to $\pm 30\%$. The energies of the peaks denoted by the vertical arrows are tabulated in Table I.

TABLE II. Parameters from shape analysis.

E_n (eV)	Resolution (eV)	FWHM ^a (eV)	σ_{obs} (mb)	σ_0 (mb)	$\Gamma \cong T_n$ (eV)	$g\Gamma_{\gamma,0}^b$ (eV)
1920	66 ± 22	420	73	75	415	0.80
9800	340 ± 120	660	96	136	560_{+10}^{-100}	$1.93_{-0.15}^{+0.1}$

^a Full width at half maximum.

^b These numbers do not include the 30% uncertainty in the normalization of the cross section.

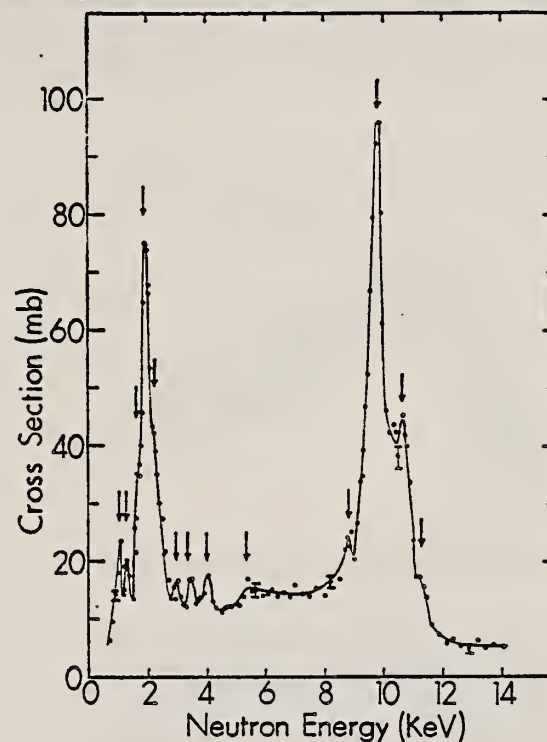


FIG. 5. Absolute photoneutron cross section $\sigma = 4\pi(d\sigma/d\Omega)_{135}$. The counting statistics for this experiment are shown for a few points by the error bars. The absolute cross-section scale is uncertain to $\pm 30\%$. The energies of the peaks denoted by the vertical arrows are tabulated in Table I.

TABLE I. Energies of peaks in the cross section.

E_L^a (keV)	$(E-Q)^b$ (keV)	E_n^c (keV)
1.05	1.28	1.30
1.25	1.51	1.54
1.65	1.94	1.97
1.92	2.22	2.26
2.20	2.54	2.58
2.95	3.36	3.42
3.40	3.84	3.91
4.00	4.49	4.57
5.35	5.92	2.06
8.80	9.55	9.71
9.80	10.62	10.8
10.65	11.50	11.7
11.30	12.2	12.4
14.70	15.9	16.2
21.0	22.3	22.7
23.5	24.9	25.4
27.0	28.5	29.0
31.0	32.6	33.2

^a E_L is the energy of the neutrons at the peaks in the cross section measured at 135° in the laboratory system. The uncertainty in flight time, which was $0.25 \mu\text{sec}$, corresponds to an uncertainty in energy (not shown in the table) of $\pm 0.01 \text{ keV}$ at $E_L = 1 \text{ keV}$ and $\pm 2 \text{ keV}$ at 31 keV .

^b $E-Q$ is the total kinetic energy in the center-of-mass system after photoejection of the neutron from the target nucleus. All resonances were assumed to belong to the Fe^{56} compound nucleus.

^c E_n is the neutron energy required to excite the same resonance by the $\text{Fe}^{56}(n,\gamma)$ reaction.

REF.

J. M. Loiseaux, J. M. Maison, and M. Langevin
J. de Physique 28, 11 (1967)

ELEM. SYM.

A

Z

Fe

56

26

METHOD

REF. NO.

67 Lo 1

JOC

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G ₂ G/	ABX	14-32	C	34	NAI-D		DST

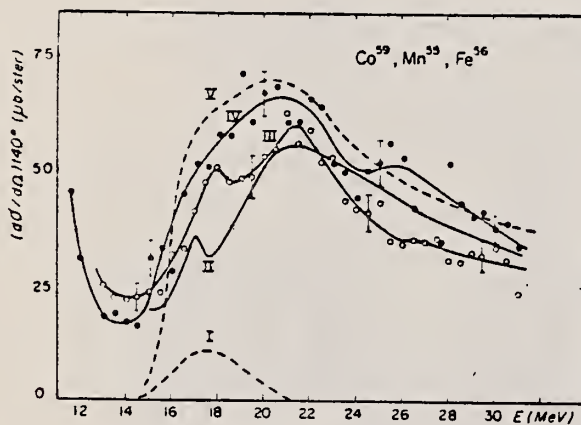


FIG. 10.

Sections efficaces différentielles de diffusion à 140° pour ⁵⁵Mn (courbe II), ⁵⁶Fe (courbe III), ⁵⁹Co (courbe IV).

Section efficace de diffusion tenseur (courbe I) et section efficace de diffusion scalaire + tenseur (courbe V) calculées avec les paramètres de Fultz et al. [16] pour ⁵⁹Co.

METHOD					REF. NO.	
					68 Ok 3	egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
G;NP	ABY	THR-20	C	20	ACT-I	

TABLE 2. THE YIELDS OF SOME (γ ,pn) REACTIONS
WITH 20 MeV BREMSSTRAHLUNG

Reaction	Half-life of product	Specific activity ^{a)} (μ Ci/mg)	Yield ($\text{mol}^{-1}\cdot\text{R}^{-1}$)
$^{54}\text{Fe}(\gamma, \text{pn})^{52}\text{Mn}$	314 d	2.5×10^{-4}	3.6×10^2
$^{66}\text{Zn}(\gamma, \text{pn})^{64}\text{Cu}$	13 hr	7.2×10^{-3}	7.5×10^3
$^{104}\text{Pd}(\gamma, \text{pn})^{102}\text{Rh}$	210 d	1.1×10^{-4}	1.7×10^3

a) The value corrected at the end of 1 hr irradiation (9.4×10^6 R/min).

REF. K. Shoda, K. Abe, T. Ishizuka, N. Kawamura, M. Oyamada,
and Baik-Nung Sung
J. Phys. Soc. Japan 25, 664 (1968)

ELEM. SYM.	A	Z
Fe	56	26

METHOD

REF. NO.

68 Sh 3

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XP	ABX	THR-23	C	13-23	SCI-I		DST

SPECTRA ALSO GIVEN

Table II. Anisotropic factor B/A of angular distributions determined by least-squares fits with $A + B \sin^2 \theta$.

⁵⁶ Fe	
$(E_{\gamma \max} = 24.0 \text{ MeV})$	
$E_{\gamma} (\text{MeV})$	B/A
2.8-3.8	-0.4 ± 0.1
3.8-5.7	-0.01 ± 0.05
5.7-6.4	0.5 ± 0.1
6.4-8.1	0.3 ± 0.1
$8.1 \leq$	0.7 ± 0.3
$2.8 \leq$	0.01 ± 0.06

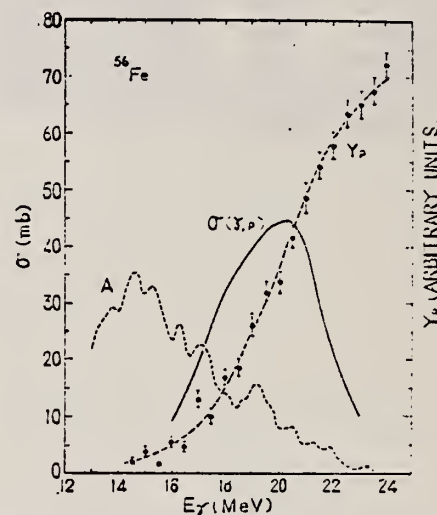


Fig. 15. Comparison among the photoproton cross sections on ⁵⁶Fe. Curve A is the cross section calculated from the present energy distribution under the assumption that the residual nucleus is completely left in the ground state. Photoproton yield curve using ZnS(Ag) scintillation counters and the cross section calculated from it are indicated by Y_p and $\sigma(\gamma, p)$ respectively.

METHOD

Page 1 of 3

REF. NO.

70 Pe 2

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E _i E _f	FMF	0-5	D	60	MAG-D		DST
				(60.2)			

⁵⁶Fe

7 2+, 1 3- STATES

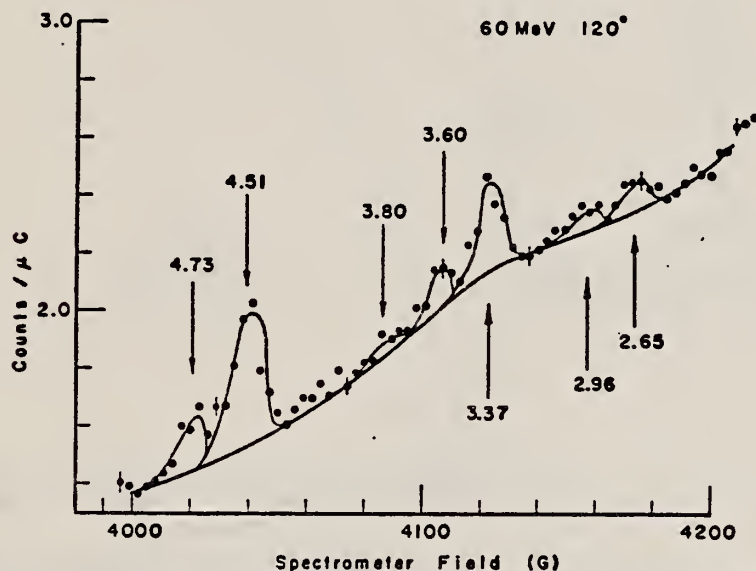


Fig. 2. A typical spectrum of electrons at a beam energy of 60.2 MeV scattered from ⁵⁶Fe. The bump in the background is due to electron showers generated by the elastic peak striking the spectrometer wall.

TABLE 2

The electromagnetic reduced matrix elements $B(EL)^\dagger$ found in the present study of ⁵⁶Fe compared to those of the earlier work at a bombarding energy of 150 MeV and the strengths generated by the use of the βR values reported from inelastic proton scattering

E2	Present work	$B(EL)^\dagger$ ($e^2 \cdot \text{fm}^2 L$)		(p, p') ^{b)}	Doppler shift ^{c)}
		Orsay (DWBA)	Orsay *) (PWBA)		
0.85 MeV	1250	1240	720	1400	892
2.65	37		112	190	17
2.96	21			32	10
3.37	41			30	55
3.60	17			46	13-64
3.80 (doublet)	10			74	8.3
4.73	19			42	
E3	Present work	$B(EL)^\dagger$ ($e^2 \cdot \text{fm}^2 L$)		(p, p')	
		Orsay (DWBA)	Orsay (PWBA)		
4.51	1.66×10^4	1.89×10^4	1.04×10^4	1.79×10^4	

³R. J. Peterson, Ann. of Phys. 53, 40 (1969).

⁴J. Bellicard and P. Barreau, Nucl. Phys. 36, 476 (1962).

²²G. G. Seaman et al., Phys. Rev. 188, 1706 (1969).

^{a)} Ref. ⁴⁾. ^{b)} Ref. ³⁾. ^{c)} Ref. ²²⁾.

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		
70 Pe 2		egf

METHOD

(PAGE 2 OF 3)

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

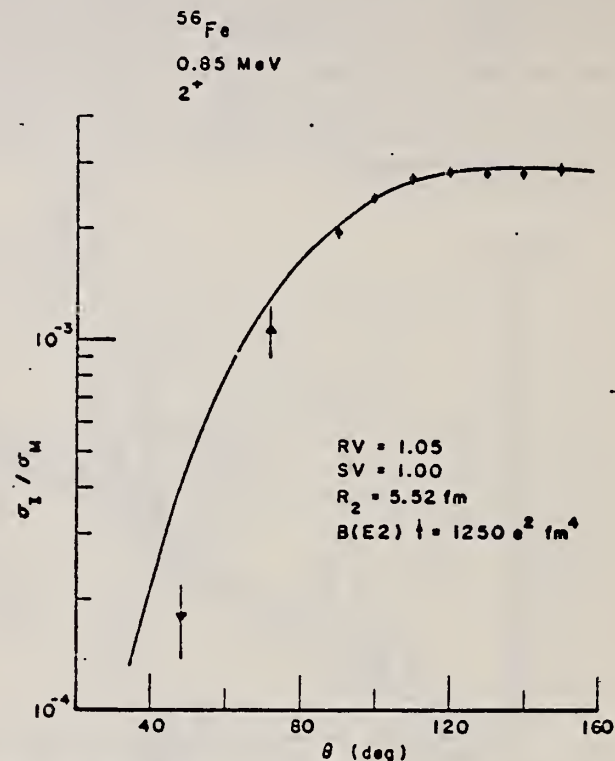


Fig. 5. The ratio of the observed cross section for populating the 0.85 MeV 2^+ state of ^{56}Fe to the Mott prediction is compared to the DWBA prediction. The parameters used for the fit are listed, as is the calculated transition radius. The data points taken at 110° at beam energies of 30.0 MeV and 42.9 MeV are plotted at the angle for which the same momentum transfer is obtained at 60.2 MeV. These two points have been adjusted to a beam energy of 60.2 MeV according to DWBA calculations.

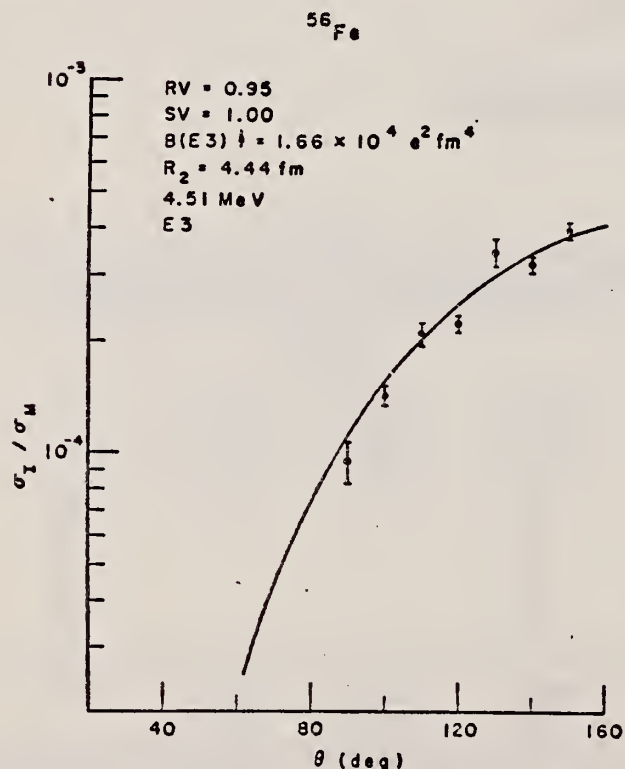


Fig. 7. The angular distribution for populating the 4.51 MeV 3^- state of ^{56}Fe is compared to the DWBA prediction.

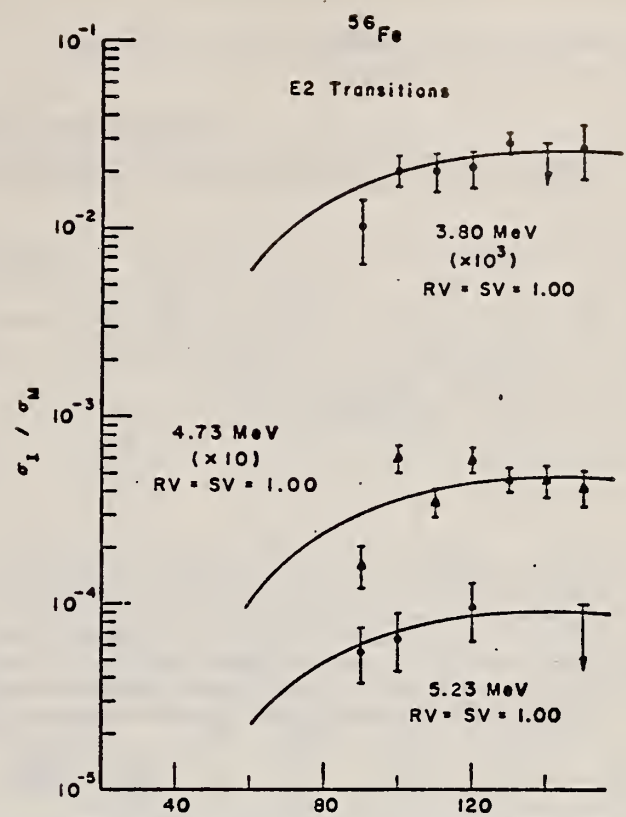


Fig. 9. The angular distributions for populating several probable 2^+ states of ^{56}Fe are shown and compared to DWBA predictions. The parameters used for the fits are listed in table 1.

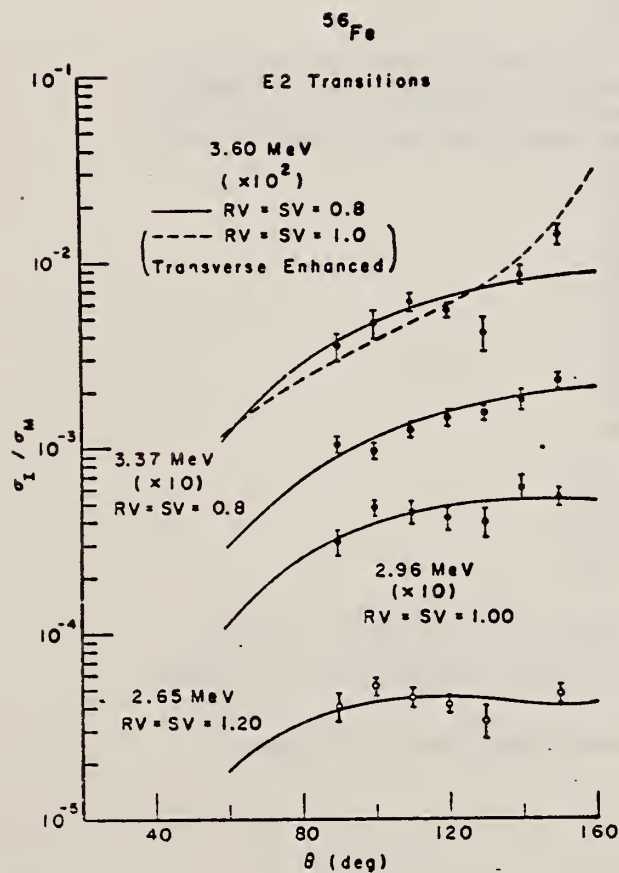


Fig. 8. The angular distributions for exciting four known 2^+ states of ^{56}Fe are shown and compared to DWBA predictions. The predicted shapes are chosen from those of fig. 6. For the 3.60 MeV state we also show the prediction obtained with an enhanced transverse electric excitation.

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		hmg
71 Ba 2		

METHOD				REF. NO.	
				71 Ba 2	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,N	ABX	11-13	C	11,13	135
		(11.2-12.7)			

TABLE VI. Resonance parameters for $^{56,57}\text{Fe}$ and $^{52,53}\text{Cr}$. For all resonances, the area under the peak in the 135° differential cross section is multiplied by 4π to yield approximate values for $g_\gamma \Gamma_{\gamma_0} \Gamma_n / \Gamma \approx g_\gamma \Gamma_{\gamma_0}$. For those resonances where J^π is known, the differential area is multiplied by the appropriate factor F from Table I to obtain Γ_{γ_0} . E_L is the laboratory neutron energy for the (γ, n) reaction and E_n is the corresponding laboratory neutron energy for a neutron-induced reaction. Column 5 labels the peak as a ground-state (GS) or excited-state (ES) transition as determined in this work alone. Clearly, if a peak is seen in a neutron-induced reaction (columns 9-11), it must be GS.

Nucleus	E_L (keV)	E_{xx} (MeV)	$g_\gamma \Gamma_{\gamma_0} \Gamma_n / \Gamma$ (eV)	GS or ES	J^π	Γ_{γ_0} (eV)	E_n (keV) (This work)	E_n (keV) from neutron-induced reactions (Ref. a) (Ref. b) (Ref. c)		
^{56}Fe	83.1	11.290	0.30	GS			88.1			
	97.6	11.304	0.47	GS			103.4			
	105	11.312	0.30				111			
	124	11.332	0.22	GS			131			
	132	11.340	0.23	GS			139			
	138	11.346	0.29	GS			146			
	164	11.373	0.74	GS			173			
	189	11.398	0.73	GS			199			
	195	11.405	0.80	GS			205			
	218	11.428	1.27	GS			229			
	228	11.438	0.31	GS			240			
	267	11.478	0.91	GS			280			
	274	11.485	1.84	GS			288			
	307	11.519	0.47				322			
	316	11.529	0.29				332			
	338	11.551	1.20	GS			354			
	347	11.560	1.13	GS			364			
	374	11.588	2.15	GS			392			
	388	11.602	1.64	GS			407			
	430	11.645	1.04	GS			450			
	450	11.666	0.95	GS			471			
	488	11.705	1.19	GS			511			
	502	11.719	1.03	GS			526			
	543	11.761	0.97	GS			568			
	576	11.795	0.34				602			
	594	11.813	1.89	GS			621			
	627	11.847	2.30	GS			656			
	705	11.927	0.37				737			

^{17(a)} C.D. Bowman, E.G. Bilpuch, and H.W. Newson, Ann. Phys. (N.Y.) 17, 319 (1962).

^{b)} See R.W. Hockenbury, Z.M. Bartolome, J.R. Tatarczuk, W.R. Moyer, and R.C. Block, Phys. Rev. 178, 1746 (1969).

^{19(c)} R.G. Steiglitz, Ph.D. thesis, Rensselaer Polytechnic Institute, 1970, (unpub.)

[over]

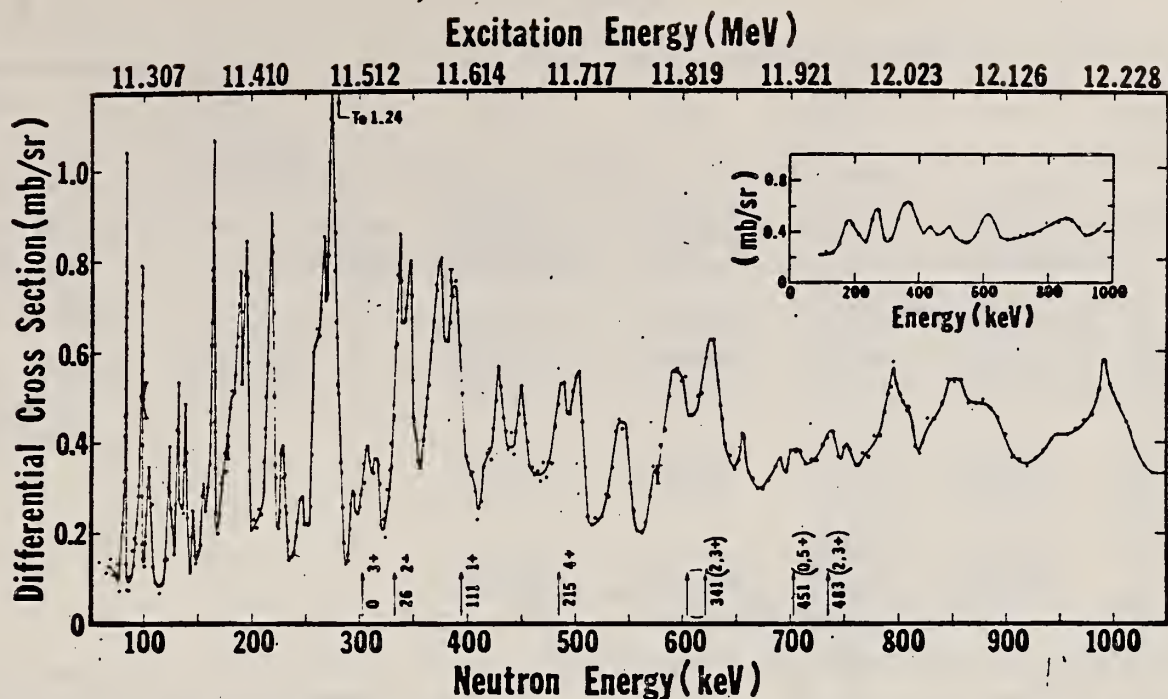


FIG. 11. The 135° differential threshold photoneutron cross section for ^{56}Fe (see caption to Fig. 4). The arrows below the data indicate the positions of isobaric analogs of low-lying states of ^{56}Mn . Next to the arrows are the values of J^π and the energy in keV of these low-lying states.

FIG. 4. The 135° differential threshold photoneutron cross section for ^{207}Pb at low energies versus the energy of the emitted neutron (lower scale) and the excitation energy (upper scale). The arrows indicate peaks which decay to excited states of the residual nucleus (ES), or peaks owing to contaminating isotopes in the photoneutron sample. The inset shows the $^{207}\text{Pb}(\gamma, n)$ cross section averaged with a square 40-keV wide smoothing function.

REF. J. Heisenberg, J. S. McCarthy and I. Sick
Nucl. Phys. A164, 353 (1971)

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		
71 He 1		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1	D	198-300	MAG-D		DST

1 = .880

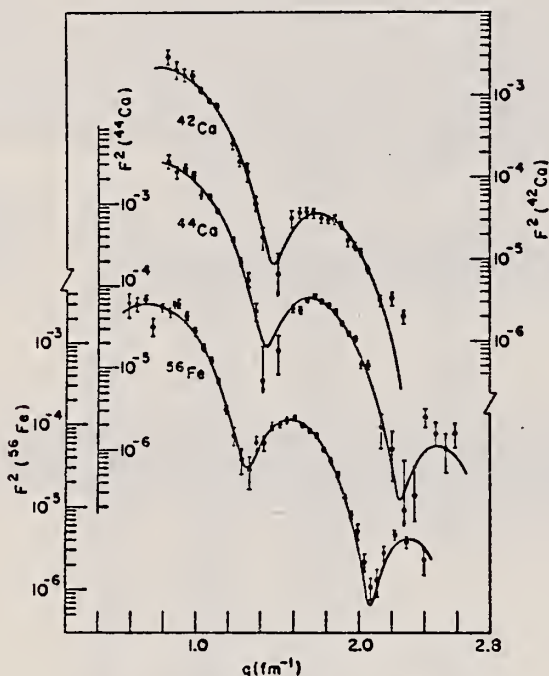


Fig. 1. Fits to the ^{42}Ca , ^{44}Ca and ^{56}Fe 2^+ levels.

[over]

TABLE 2
Inelastic parameters for 2⁺ levels

Isotope	E [*] (MeV)	B(E2) Coulomb Excit. (e ² · fm ⁴)	Shape	c _{ir} ^{a)} (fm)	z _{ir} ^{a)} (fm)	Fitted B(E2) (e ² · fm ⁴) ^{b)}	R _{ir} ^{a)} (fm)	B(E2)(e ² · fm ⁴) heavy-particle scattering
⁴² Ca	1.520	364 ± 82 ⁹⁾	2	3.541 ± 0.025	1.459 ± 0.020	320 ± 20	4.619 ± 0.030	476 ± 74 ¹⁹⁾
⁴⁴ Ca	1.160	350 ± 70 ¹⁰⁾	2	3.691 ± 0.027	1.428 ± 0.020	480 ± 30	4.704 ± 0.030	507 ± 100 ¹⁹⁾
			1	3.454 ± 0.025	0.690 ± 0.010	1270 ± 85	5.553 ± 0.030	
⁴⁶ Ti	3.259	830 ± 170 ¹⁴⁾	2	3.807 ± 0.014	1.397 ± 0.010	54 ± 10	4.763 ± 0.017	867 ²⁰⁾
			1			740 ± 20		738 ¹¹⁾
⁴⁸ Ti	0.984	560 ± 100 ¹³⁾	2	3.562 ± 0.014	0.669 ± 0.005	1680 ± 50	5.510 ± 0.020	788 ± 120 ¹⁹⁾
			1			537 ± 15		673 ¹¹⁾
⁵⁰ Ti	2.420	700 ± 140 ¹⁴⁾	2	3.539 ± 0.014	0.633 ± 0.005	1110 ± 30	5.321 ± 0.020	659 ²⁰⁾
			1			49 ± 8		57 ± 10 ¹⁹⁾
⁵⁶ Fe	1.580	240 ± 20 ¹³⁾	2	3.768 ± 0.014	1.255 ± 0.010	307 ± 10	4.567 ± 0.017	349 ²⁰⁾
			1			515 ± 17		260 ²¹⁾
⁵⁶ Fe	4.320	877 ± 70 ^{a)}	2	4.048 ± 0.024	1.357 ± 0.014	51 ± 8	4.919 ± 0.025	431 ²⁴⁾
			1			945 ± 45		72 ²⁴⁾
	0.880			3.878 ± 0.024	0.651 ± 0.006	1570 ± 70	5.454 ± 0.030	
Present experiment								

^{a)} Errors do not reflect any model dependence.

^{b)} Given errors do not include the 6% error of normalization.

^{c)} Average for B(E2) formed from values of refs. ¹³⁻¹⁸⁾.

13) J. Simpson, J. Cookson, D. Eccleshall and M. Yates, Nucl. Phys. 62 (1965) 385

14) G. M. Temmer and N. P. Heydenburg, Phys. Rev. 104 (1956) 967

15) D. S. Andreyev, A. P. Grinberg, K. I. Erokhina and I. Kh. Lemberg, Nucl. Phys. 19 (1960) 400

16) F. R. Metzger, Nucl. Phys. 27 (1961) 612

17) W. H. Kelly and G. B. Beard, Nucl. Phys. 27 (1961) 183

18) R. B. Begzhanov, A. A. Islamov, D. K. Kaipov and Yu. K. Shubnyi, JETP (Sov. Phys.) 17 (1963) 94

REF.

A.S. Litvinenko, N.G. Shevchenko, A.Yu. Buki, P.L. Kondrat'ev,
G.A. Savitskii, A.A. Khomich, V.M. Khvastunov, I.I. Chkalov
Ukr. Fiz. Zhur. 17, 1197 (1972)

ELEM. SYM.

A

Z

Fe

56

26

METHOD

REF. NO.

72 Li 3

hmg

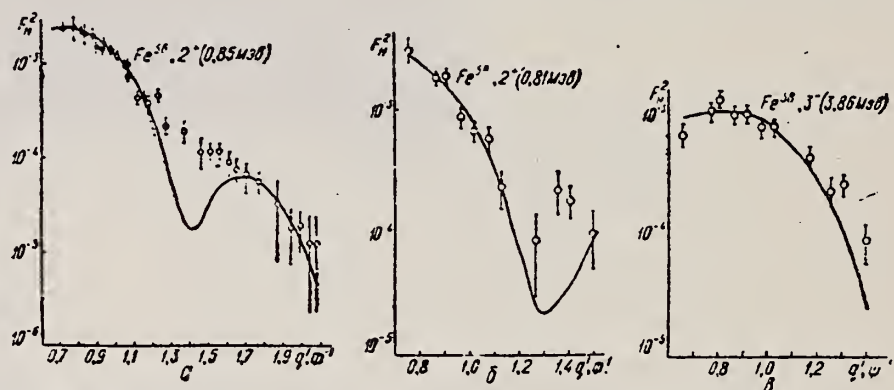
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, eV	FMF	1	D	150,225	MAG-D		DST

Таблица 1

B(EL) LEV .85

Параметры фермиевского распределения плотности заряда
(с—радиус полуспада плотности, t—диффузность ядра)

Ядро	с, ф	t, ф
Fe ⁵⁴	4.012 ± 0.007	2.316 ± 0.011
Fe ⁵⁶	3.971 ± 0.013	2.608 ± 0.020
Fe ⁵⁸	4.027 ± 0.019	2.530 ± 0.031
Ni ⁶²	4.149 ± 0.011	2.506 ± 0.016



Формфакторы F_2 и F_3 -переходов в ядрах Fe^{54} (а) и Fe^{56} (б, в). Сплошные кривые — расчет по вибратонной модели в высокоэнергетическом приближении: \odot — 150 Мэв; \circ — 225 Мэв. Δ — данные работы [6]; пунктирная кривая — расчет в борновском приближении [6].

Таблица 2

Ядро	E_{λ} , Мэв	J^{π}	Данные настоящей работы	Данные других работ		Литература
			$B(EL) \uparrow$, $e^2 \text{м}^2$	$B(EL) \uparrow$, $e^2 \text{м}^2$	Тип эксперимента и метод определения	
Fe ⁵⁴	1.4	2 ⁺	531.9 ± 32.4	533	(ee'), борновское приближение	[6]
	4.85	3 ⁻	4563 ± 410	4390		
Fe ⁵⁶	0.85	2 ⁺	678.1 ± 47.5	720	(ee'), борновское приближение	[7]
				1250 ± 270	искаженные волны	
				1240	борновское приближение	
Fe ⁵⁸	0.81	2 ⁺	943.2 ± 79		кулоновское возбуждение	[8]
	3.86	3 ⁻	13880 ± 1260			
Ni ⁶²	1.17	2 ⁺	618.6 ± 42.1	877 ± 11	(ee'), искаженные волны	[9]
	3.75	3 ⁻	14359 ± 962	20100 ± 540		

REF. Y. Torizuka, Y. Kojima, T. Saito, K. Itoh, A. Nakada,
S. Mitsunobu, M. Nagao, K. Hosoyama, S. Fukuda
PICNS-72, p.171 Sendai

ELEM. SYM.	A	Z
Fe	56	26

METHOD

REF. NO.

72 To 6

hvm

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,E/	SPC	0- 37	D	250	MAG-D		35

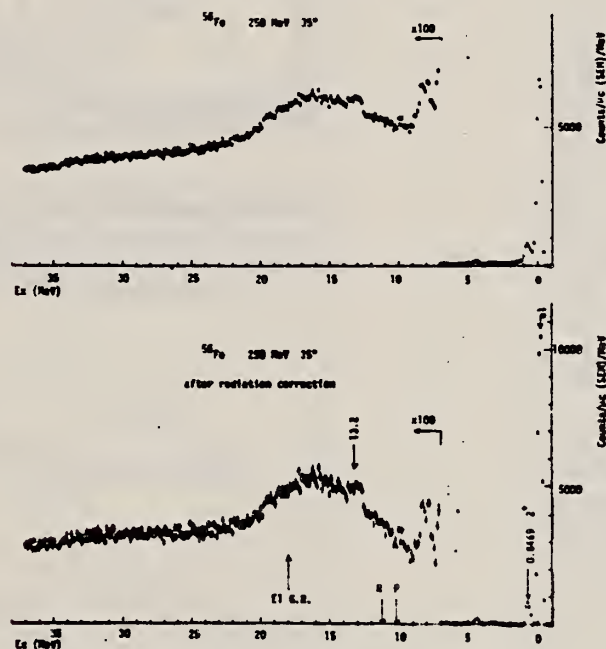


Fig. 1. The spectra of ^{56}Fe obtained at 250 MeV and 35° . The upper figure corresponds to the raw spectrum and the lower one to the spectrum after radiation tail subtraction. The peak of the E1 giant resonance is indicated at 18 MeV and the proton or neutron emission threshold energy is shown by the arrows.

REF.

Y. Torizuka, Y. Kojima, T. Saito, K. Itoh, A. Nakada,
S. Mitsunobu, M. Nagao, K. Hosoyama, S. Fukuda, H. Miura
PICNS-73, Vol.I, p.675 Asilomar

ELEM. SYM.	A	Z
Fe	56	26

METHOD

REF. NO.

73 To 1

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	10- 35	D	150, 250	MAG-D		DST

FMF OF 16.1 MEV LEV

Table II. $B(EL)$, $|M_{if}|^2$ and fractions of energy-weighted sum rules (EWSR) with $T=0$ in ^{56}Fe .

E_x (MeV)	J^π	$B(E2)_{\text{or}} |M_{if}|^2$	$\frac{E_x \cdot B(E2)}{\text{EWSR}}$	$\frac{E_x \cdot |M_{if}|^2}{\text{EWSR}}$
16.1	2^+	$672 \text{ e}^2 \text{ fm}^4$	0.80	
16.1	0^+	1370 fm^4		1.43

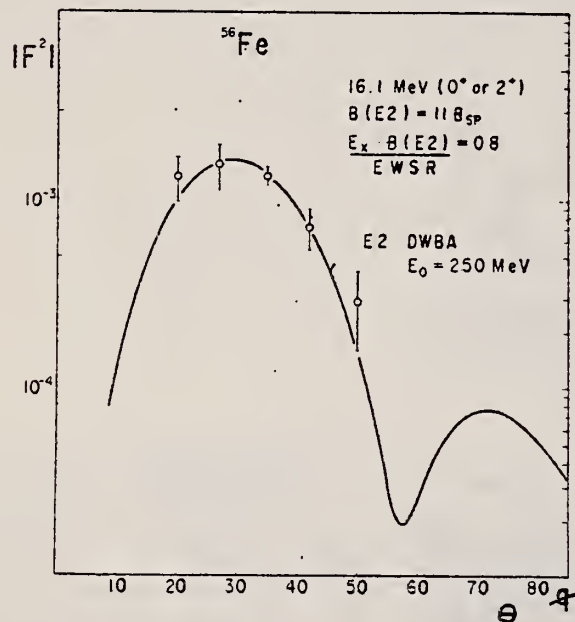


Fig. 4. The form factor for the 16.1-MeV state.

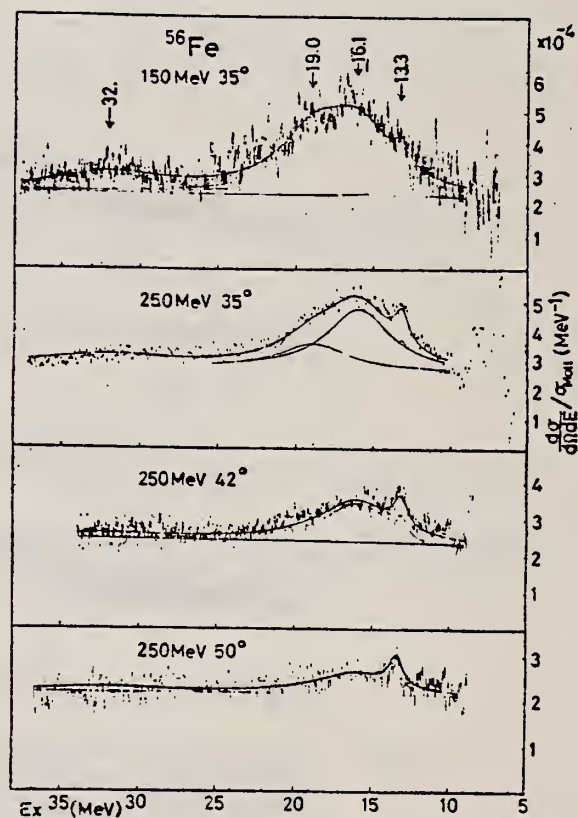


Fig. 3. Inelastic electron scattering spectra of ^{56}Fe in the range from 10 to 35 MeV. The arrows indicate peaks at 13.3, 16.1, 19.0, and ~ 32 MeV.

METHOD

REF. NO.

73 Ve 3

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	11- 14	C	11, 13	TOF-D		93
		(11.20-13.27)		(11.71, 13.27)			

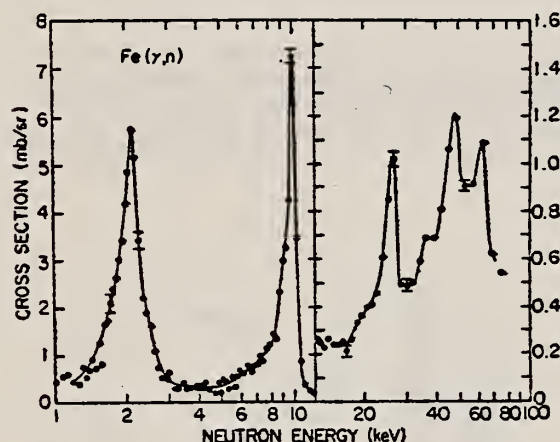


FIG. 4. The 93° differential threshold photoneutron cross section for $\text{Fe}(\gamma, n)$ versus the energy of the emitted neutron. Electrons of 13.27-MeV and 3% resolution were incident on the bremsstrahlung converter, and the time analyzer was set at 250 nsec per channel.

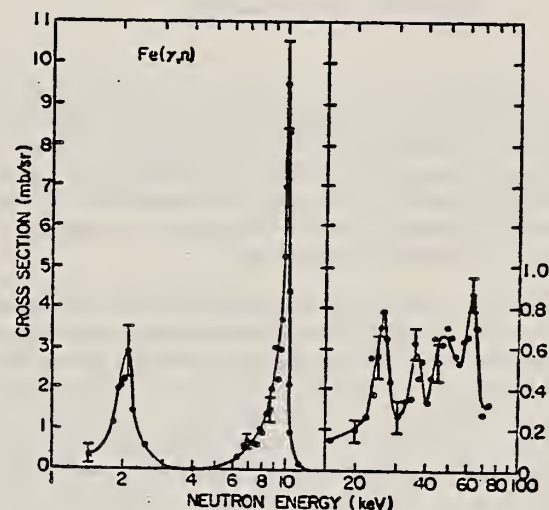


FIG. 5. The 93° differential threshold photoneutron cross section for $\text{Fe}(\gamma, n)$ versus the energy of the emitted neutron. Electrons of 11.71-MeV and 1% resolution were incident on the bremsstrahlung converter, and the time analyzer was set at 62.5 nsec per channel.

TABLE II. Resonance parameters from threshold $\text{Fe}(\gamma, n)$ data.

Neutron energy (keV)	Width at half maximum (keV)	Experimental resolution (keV)		Deexcitation to ground state (G) or to excited states (E) of ^{55}Fe	$\Gamma \approx \Gamma_n$ (keV)	$g\Gamma_\gamma\Gamma_n/T$ (eV)
		Fig. 4	Fig. 5			
2.1	0.40 (Fig. 4)	0.052	0.039	E(=0.411 MeV)	0.40	0.68
~2.5		0.066	0.050	?		
10.0	0.4 (Fig. 5)	0.51	0.36	G	~0.17	1.97

ELEM. SYM.	A	Z
Fe	56	26

METHOD	REF. NO.	
	76 Ab 9	hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	11-14	C	11-14	TOF-D		78

The reaction $^{56}\text{Fe}(\gamma, n)^{55}\text{Fe}$ near threshold

A. I. Abramov, V. Ya. Kitaev, A. V. Rogov, and M. G. Yutkin

Physics and Power Engineering Institute
(Submitted February 23, 1976)
Yad. Fiz. 24, 871-872 (October 1976)

PACS numbers: 25.20.+y, 27.40.+z

Experiments on the (γ, n) reaction near threshold in iron nuclei have been carried out repeatedly by various groups of investigators.^[1-5] The existence of several strong resonances in the region of neutron energies up to 20 keV makes this reaction very convenient for development of technique and for comparison of results obtained in different laboratories.

Up to this time all of the measurements in this energy region have been carried out exclusively with samples of natural iron. Here it has been assumed that at least the strongest resonances at $E_n \approx 2$ and 10 keV are due to the (γ, n) reaction in the isotope ^{56}Fe . In regard to the weaker resonances, it has been impossible to exclude with a sufficient degree of reliability their connection with the (γ, n) reactions in the other isotopes of iron, particularly ^{57}Fe , and therefore the assignment of them to the reaction $^{56}\text{Fe}(\gamma, n)^{55}\text{Fe}$ (as was done in all of the studies cited) is only hypothetical in nature.

In order to check the validity of this assumption, we have measured the cross section for the reaction $^{56}\text{Fe}(\gamma, n)^{55}\text{Fe}$ with a sample containing the isotope ^{56}Fe in the amount 99.7% (91.7% in natural iron). The sample had the shape of a disk 75 mm in diameter and weight 218.4 grams. The experimental method has been described in detail elsewhere.^[5] The figure shows the experimental results in the neutron energy region from 2 to 130 keV, obtained with a bremsstrahlung maximum energy of 13.3 MeV. The arrows denote the location of the resonances according to the data of our earlier work.^[5] From the results presented it follows that the previously observed resonances at $E = 2.16, 10.15, 26.5, 43.5, 49.8, 63.8$, and 109.6 eV can be assigned definitely to the (γ, n) reaction in the isotope ^{56}Fe . The resonances at $E_n = 6.85, 9.59, 20.5$, and 31.6 keV did not appear in our measurements. At the same time, in the regions 3-6 and 13-17 keV some structural de-

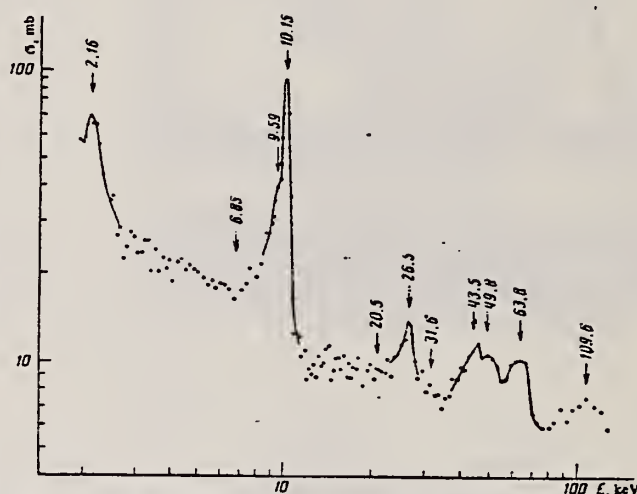


FIG. 1. Differential cross sections for the reaction $^{56}\text{Fe}(\gamma, n)^{55}\text{Fe}$ for $E_{\gamma, \text{max}} = 13.3$ MeV, measured at an angle 78° and multiplied by 4π .

tails appear which can be compared with the resonances of other studies.^[1,2,4] However, this question can be finally answered only after a more detailed study.

- ¹C. D. Bowman, G. S. Sildbu, and B. L. Berman, Phys. Rev. 163, 951 (1967).
- ²R. J. Baglan, C. D. Bowman, and B. L. Berman, Phys. Rev. C3, 672 (1971).
- ³A. I. Abramov, V. Ya. Kitaev, Yu. Ya. Stavitskiĭ, and M. G. Yutkin, Neutronaya fizika (Neutron Physics), Part I, Kiev, Naukova dumka, 1972, p. 289.
- ⁴V. V. Verbinskiĭ, Hans Weber, and R. E. Sund, Phys. Rev. C8, 1002 (1973).
- ⁵A. I. Abramov, V. Ya. Kitaev, and M. G. Yutkin, Yad. Fiz. 20, 438 (1974) [Sov. J. Nucl. Phys. 20, 236 (1975)].

Translated by Clark S. Robinson

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		hmg
76 Gr 3		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,PI+	SPC	150-500	C	500	EMU-I		DST
G,PI-	SPC	150-500	C	500	EMU-I		DST

The energy spectra of charged photopions from ^{54}Fe , ^{56}Fe , and ^{58}Ni targets irradiated with bremsstrahlung of maximum energy 500 MeV have been measured at photopion-emission angles of 30, 60, 90, 120, and 150° in the lab system over the kinetic-energy range from 15 to 80 MeV. Isotope effects are found in the π^- yields at 30, 60, and 90°. At all angles and energies, the π^+ yields are the same for all three targets within the experimental error.

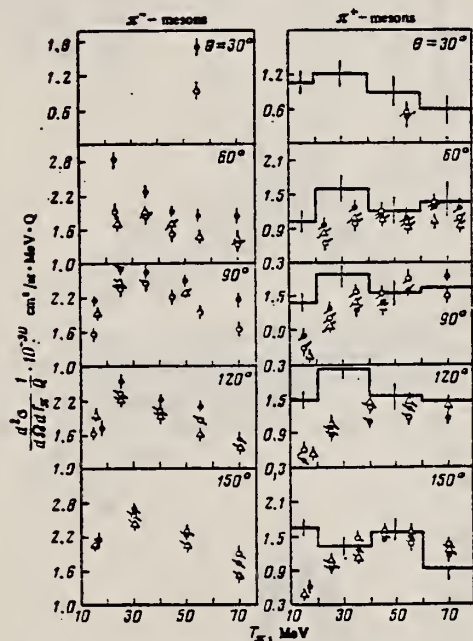


FIG. 1. Energy spectra of charged photopions from ^{54}Fe , ^{56}Fe , and ^{58}Ni targets (open circles, black circles, and triangles, respectively) at $E_0=500$ MeV. The error bars represent statistical errors. The histograms on the π^+ -meson plots represent the results of cascade-model calculations for ^{56}Fe .

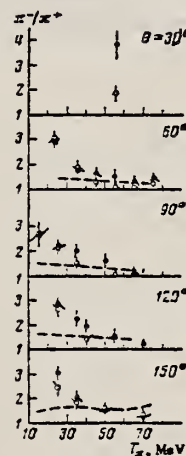


FIG. 2. The π^-/π^+ yield ratios for ^{56}Fe (black circles) and ^{54}Fe (open circles) targets vs photopion kinetic energy. The dashed curves were calculated with Eq. (4).

REF.

D.G. Rickel, C.P. Cameron, R.D. Ledford, N.R. Roberson,
H.R. Weller, D.R. Tilley
Phys. Rev. C14, 338 (1976)

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		
76 Ri 2		hmg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
A,G	ABX	14- 22	D	7- 16	NAI-D		90
P,G	ABX	14-22	D	3-12	NAI-D		90

A comparison is made between the yield curves of the measured $^{56}\text{Fe}(\alpha, \gamma_0)$ and $^{55}\text{Mn}(p, \gamma_0)$ reactions in the giant dipole resonance region of ^{56}Fe ($E_x = 14.0$ to 21.5 MeV) to determine if the gross differences can be interpreted as being due to isospin effects. Above 18 MeV the yield of (γ, α_0) , determined by the principle of detailed balance, is observed to drop below the value obtained when the energy dependence of the transmission coefficients is removed. This leads to the conclusion that while the diminished yield in the (γ, α_0) channel may be due to the failure to populate the isospin forbidden T_2 states, other effects cannot be ruled out.

TABLE II. Comparison of yields in proposed T_2 and T_1 regions of the GDR for both proton and α capture. The energy region extends from 14.5 to 21.5 MeV with the division between the T_2 and T_1 region assumed to occur at 18.7 MeV.

	(γ, p_0) observed (mb MeV)	(γ, α_0) observed (mb MeV)	(γ, α_0) Theory 2 (mb MeV)
T_2 yield	2.00	2.31	2.57
T_1 yield	0.72	0.29	0.82
T_2/T_1	0.36	0.13	0.32

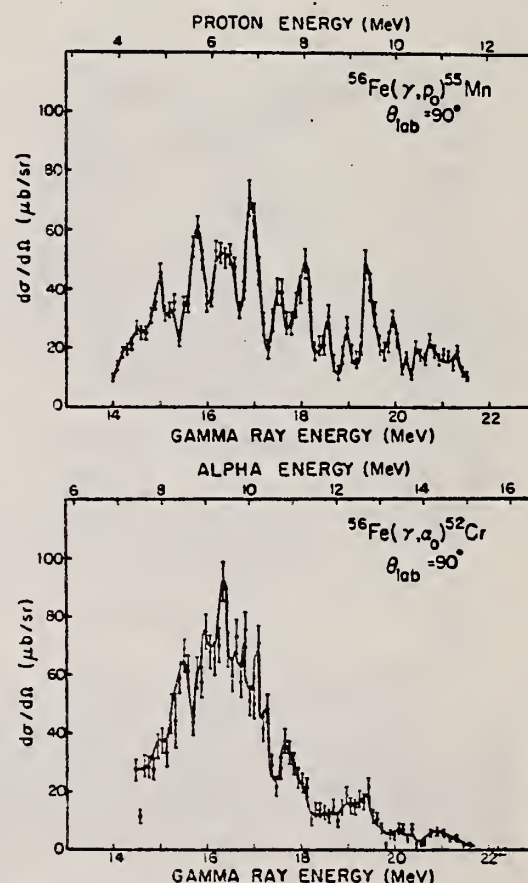


FIG. 2. The 90° yield curves for $^{56}\text{Fe}(\gamma, p_0)$ and $^{56}\text{Fe}(\gamma, \alpha_0)$ obtained from the data by the principle of detailed balance. The error bars represent the statistical errors of the data points. The solid lines are smooth curves drawn through the data points.

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		
77 Ra 3		egf

METHOD						REF. NO.		
						77 Ra 3		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE	
			TYPE	RANGE	TYPE	RANGE		
G,N	SPC	14-26	C	15-26	SCI-D		UKN	

FAST NEUTS

TABLE 3

Relationship between the structure in the energy spectra and the structure in the photoneutron cross section for ^{56}Fe

Position of peak in neutron energy spectrum ϵ						Position of resonance ^{56}Fe E_R (MeV)	Position of level ^{55}Fe *)	
$E_{\gamma \text{ max}}$ (MeV)							$E = E_R - \bar{\epsilon}_m - E_{\text{re}}^b)$	
18.5	20.2	21.2	23.0	25.0	26.2			
4.4	4.5	4.2	4.2	4.2		16.0	0.4	
5.1	5.2	5.3	5.3	5.5	5.4	18.1		1.5
6.2	6.4		6.4	6.4	6.4	18.1	0.4	
	5.9	6.0	6.0	5.9	6.0	19.8		2.5
	7.1	7.1	7.0	7.4	7.4	19.8		1.3
		8.6	8.6		8.4	19.8	0.1	
			9.6	9.2	9.4	21.6		0.8
			10.0	9.9	10.0	21.6	0.2	
				10.9	11.0	24.7		2.3
						mean value:		
						0.1	0.33	0.8 1.4 2.4
						spectroscopic data:		
						0	0.41	0.93 1.32 2.54

*) A nuclear recoil correction has been introduced.

b) $\bar{\epsilon}$ is ϵ averaged by $E_{\gamma, \text{max}}$.

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		hg
78 Ma 10		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G,PN	ABY	20-68	C	30-68	ACT - I		4PI
G,AN	ABY	20-68	C	30-68	ACT - I		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

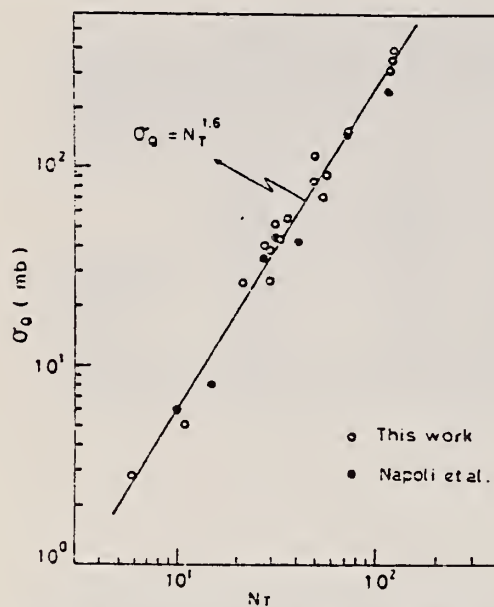


Fig. 2. Yield per equivalent quanta versus target neutron number.

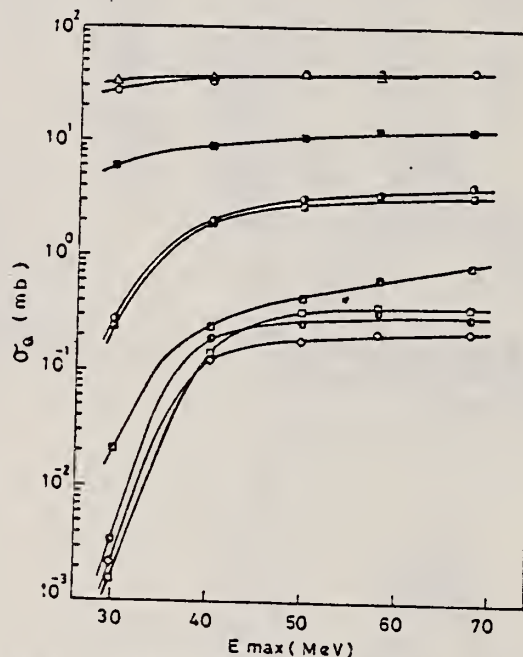


Fig. 5. Activation yield curves for the reactions on Cr, Mn and Fe.

○ $^{52}\text{Cr}(\gamma, n)^{51}\text{Cr}$, ● $^{50}\text{Cr}(\gamma, pn)^{48}\text{V}$, ⊙ $^{50}\text{Cr}(\gamma, 2n)^{48}\text{Cr}$,
△ $^{55}\text{Mn}(\gamma, n)^{54}\text{Mn}$, ▣ $^{57}\text{Fe}(\gamma, p)^{56}\text{Mn}$, ▤ $^{54}\text{Fe}(\gamma, pn)^{52}\text{Mn}$,
▥ $^{56}\text{Fe}(\gamma, pn)^{54}\text{Mn}$, □ $^{56}\text{Fe}(\gamma, 2n)^{51}\text{Cr}$, ◇ $^{54}\text{Fe}(\gamma, 2n)^{52}\text{Fe}$.

(over)

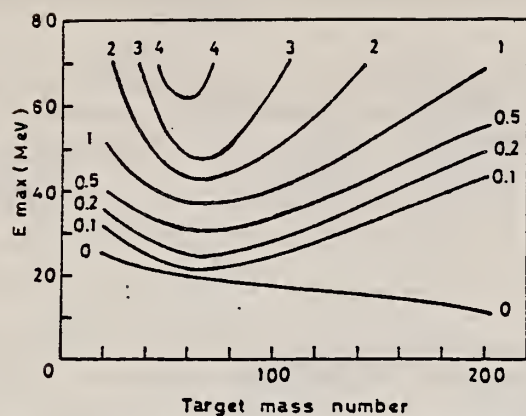


Fig. 11. Yields of the (γ, pn) reactions as a function of bremsstrahlung maximum energy and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

ELEM. SYM.	A	Z
Fe	56	26
79Ku4		hg

METHOD				REF. NO.	
				79Ku4	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,G	LFT	6-12	C	14	DST

7 LEVELS

Abstract: The resonance scattering of electron bremsstrahlung from natural chromium and iron targets has been studied for photon energies up to 12 MeV. Seven γ -transitions of energies higher than 7 MeV were observed for each of the targets, which suggests seven resonant levels in each of ^{52}Cr and ^{56}Fe at excitation energies above 7 MeV. The spins of these levels were all assigned to be 1 from the relative yields at scattering angles of 125° and 150° . Radiative widths of these levels were obtained. A discussion is made about the possibility that these levels are T_+ components of the M1 giant resonance in ^{52}Cr and ^{56}Fe .

E NUCLEAR REACTIONS ^{52}Cr , $^{56}\text{Fe}(\gamma, \gamma)$ bremsstrahlung $E_\gamma = 14$ MeV; measured E_γ , $I_\gamma(\theta = 125^\circ, 150^\circ)$; ^{52}Cr , ^{56}Fe deduced levels, J , Γ_γ . Natural targets.

TABLE 2
Electromagnetic transitions in ^{11}B used for calibration of $N\epsilon\Omega$ ^{a)}

Initial state	J^π	Γ (eV)	Branching ratios (%) to final states ^{b)}			
			g.s.	2.125	4.445	5.021
4.445	$\frac{1}{2}^-$	0.610 ± 0.030	100 ^{c)}			
5.021	$\frac{1}{2}^-$	1.80 ± 0.13 ^{d)}	84 ± 2 ^{e)}	16 ± 2 ^{f)}		
7.286	$\frac{1}{2}^+$	1.17 ± 0.26 ^{d)}	87 ± 2		5.5 ± 1	7.5 ± 1
8.920 ^{g)}	$\frac{1}{2}^-$	4.20 ± 0.52 ^{d)}	95 ± 1		5 ± 0.5	

^{a)} Ref. ⁹⁾ except where shown.

^{b)} Ref. ⁹⁾.

^{c)} $\delta = -0.19 \pm 0.15$ [ref. ⁹⁾].

^{d)} Ref. ⁷⁾.

^{e)} $\delta = 0.03 \pm 0.05$ [ref. ⁹⁾].

^{f)} $\delta = -0.05 \pm 0.20$ [ref. ⁹⁾].

^{g)} $\delta = -0.11 \pm 0.04$ [ref. ¹⁰⁾].

TABLE 3
Electromagnetic transitions in ^{24}Mg used for calibration of $N\epsilon\Omega$ ^{a)}

Initial state	J^π	Γ (eV)	Branching ratios (%) to final states	
			g.s.	1.369
9.966	1^+	8.8 ± 2.3	65 ± 2	35 ± 2
10.712	1^+	19.9 ± 1.8	78 ± 4	22 ± 4

^{a)} Ref. ¹¹⁾.

TABLE 4
Summary of the experimental results of ^{52}Cr

Level energy (MeV)	J	Γ (eV)	$B(\text{M1}, 1^+ \rightarrow 0^+) \text{ (}\mu_N^2\text{)}$
7.524	1	0.97 ± 0.23	0.20
7.729	1	1.75 ± 0.32	0.33
7.896	1	5.68 ± 0.80	1.00
8.091	1	1.60 ± 0.35	0.26
9.138	1	2.93 ± 0.51	0.33
9.211	1	2.76 ± 0.59	0.31
9.783	1	4.01 ± 0.61	0.37

^{a)} Deduced on the assumption of 100% ground-state transition.

^{b)} Deduced on the assumption of even parity.

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		
80 A1 1		hg

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
E,E/	RLX	0-70	D	100-373	MAG-D		DST

Inelastic-electron-scattering cross sections for ^{56}Fe have been measured in the continuum region. The longitudinal and transverse inelastic response functions have been determined for vector momentum transfers, q , from 210–410 MeV/c and for energy losses $0 < \omega \leq 220$ MeV.

Q 210-410 MEV/C

PACS numbers: 25.30.Cg, 27.40.+z

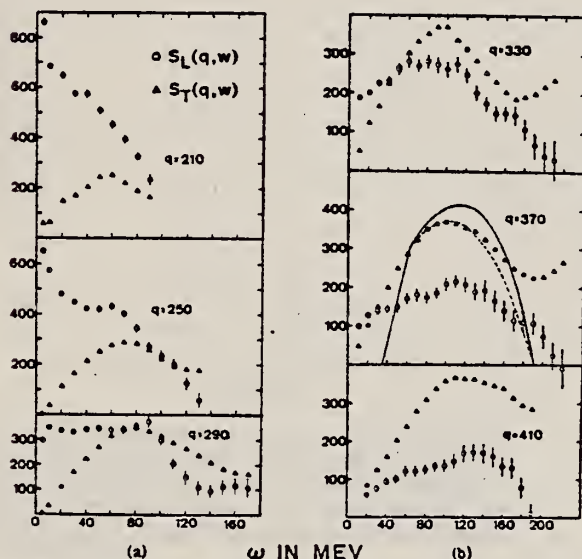


FIG. 1. (a), (b) S_L (circles) and S_T (solid triangles) for Fe. The errors are smaller than the points unless otherwise shown and include statistics only. The overall data has an uncertainty of $\approx 3\%$ coming from the normalization to the proton. All q values are in units of MeV/c; the transverse and longitudinal response functions are dimensionless. For the data at $q = 370$ MeV/c the results for the Fermi-gas calculations are shown; the dashed line represents S_T , the solid line S_L .

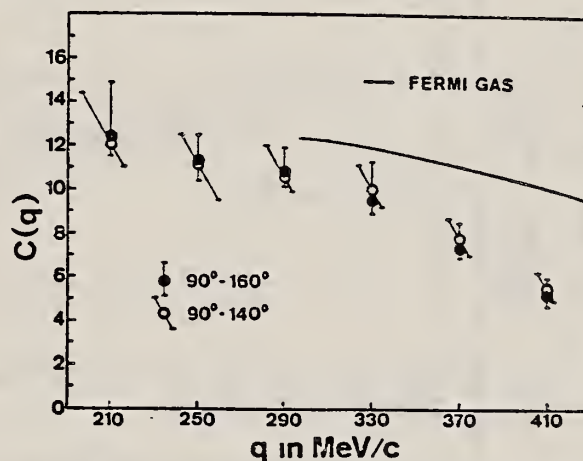


FIG. 2. The Coulomb sum rule $C(q)$ for Fe compared with prediction for a Fermi gas over the range of experimentally available q .

ELEM. SYM.	A	Z
Fe	56	26

METHOD	REF. NO.	
	80 Mc 3	hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	ABX	10*200	D	100-999	MAG-D		DST

Abstract: Inclusive electron scattering from the nuclei ^{56}Fe and ^3He has been measured over a wide range of incident energy and momentum transfer. The data is used to separate the longitudinal and transverse response functions. The two-nucleon correlation function and the momentum distribution of the internal nucleons is compared to the data.

999=14 GEV, *E LOSS

NUCLEAR REACTIONS: (e,e') on ^{56}Fe , ^3He Incident Energies $E = 0.1$ to 14 GeV; measured scattered electron at energy loss $\omega = E - E'$ of 0-2 GeV. Deduced momentum distribution.

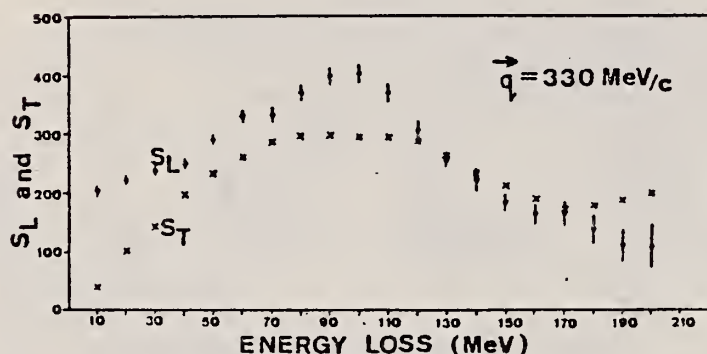


Fig. 3 The transverse (S_T) and longitudinal (S_L) response functions at constant $\vec{q} = 330 \text{ MeV/c}$ for ^{56}Fe .

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		
80 Sk 5		hg

METHOD					
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
E, A	ABX	7-50	D	26-50	DST
The cross section $^{56}\text{Fe}(e, \alpha)$ has been measured as a function of α energy, lab angle, and incident electron energy. The analyses of these data using distorted-wave Born approximation virtual photon spectra have been performed in the framework of models suggested by the data. We find that the (e, α) channel exhausts a sizable percentage of the E2 isoscalar sum rule.					

VIRT PHOTON ANAL

[NUCLEAR REACTIONS $^{56}\text{Fe}(e, \alpha)$ measured $\sigma(E_0, E_\alpha, \theta_\alpha)$, obtained $\sigma(e, \alpha)$ and determined $\sigma^{E1}(\gamma, \alpha)$ and $\sigma^{E2}(\gamma, \alpha)$.]

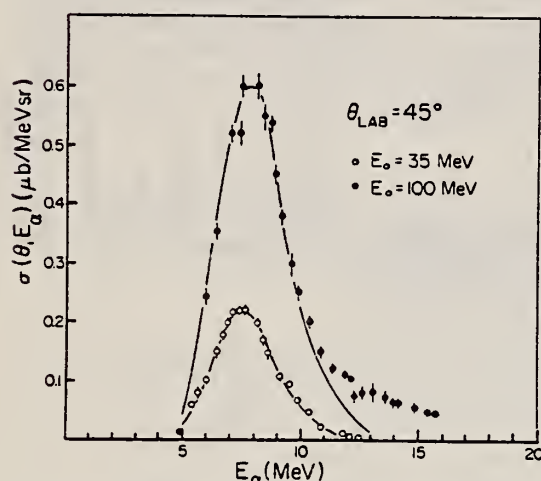


FIG. 2. Measured differential cross sections at $\theta_{\text{LAB}} = 45^\circ$ for incident electron energies of 35 and 100 MeV. The solid lines are fits using the statistical model employed in our earlier studies of the (e, α) reaction from various nuclei. These fits result in a nuclear temperature of 0.3 MeV.

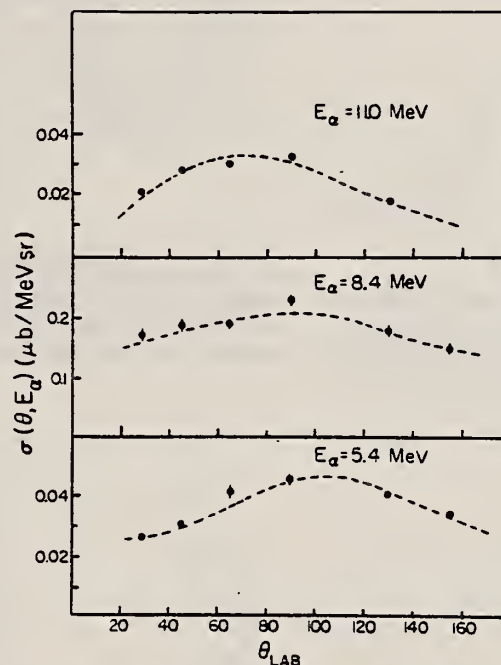


FIG. 3. Representative angular distributions that show the shift from backward to forward angles of α particles.

TABLE I. E2 integrated cross sections and resonance parameters determined by the isochromat analysis of Sec. IV B.

	Trapezoidal ^a integration	2nd order fit ^a integration	Lorentz line shape	Breit-Wigner line shape
$\int \sigma dE$ (mbMeV)	3.6 ± 0.3	3.8 ± 0.3	3.9 ± 0.1	3.9 ± 0.1
$\int \frac{\sigma dE}{E^2}$ ($\mu\text{b}/\text{MeV}$)	11.0 ± 1.0	11.3 ± 0.9	11.1 ± 1.6	11.1 ± 1.5
% of E2 sum rule ^b	28 ± 3	29 ± 2	29 ± 4	29 ± 4
E_R (MeV)			17.9 ± 0.2	18.1 ± 0.2
Γ (MeV)			2.8 ± 0.3	2.9 ± 0.3
σ_0 (mb)			1.00 ± 0.07	1.00 ± 0.06

^aReference 13.

^bWe have used the value $0.22Z^2/A^{1/3}$.

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TABLE II. E2 integrated cross sections and resonance parameters determined by the total cross section analysis of Sec. IV C.

Line shape	σ_0 (mb)	Γ (MeV)	E_R (MeV)	$\int \sigma dE$ (mbMeV)	$\int \frac{\sigma dE}{E^2}$ ($\mu\text{b}/\text{MeV}$)	% of E2 sum rule
Lorentz	a	0.72 ± 0.02	3.1	3.04 ± 1.55	8.74 ± 2.82	22 ± 7
	b	0.99 ± 0.03	2.2 ± 0.2	3.14 ± 0.30	9.12 ± 0.42	23 ± 1
Breit-Wigner	a	0.75 ± 0.02	3.1	2.99 ± 1.40	8.92 ± 2.84	23 ± 7
	b	1.00 ± 0.02	2.3 ± 0.1	3.13 ± 0.23	9.27 ± 0.15	24 ± 1

^aFit constrained to the E2 values of Γ and E_R found from the angular distribution analysis.
^bUnconstrained fit.

(over)

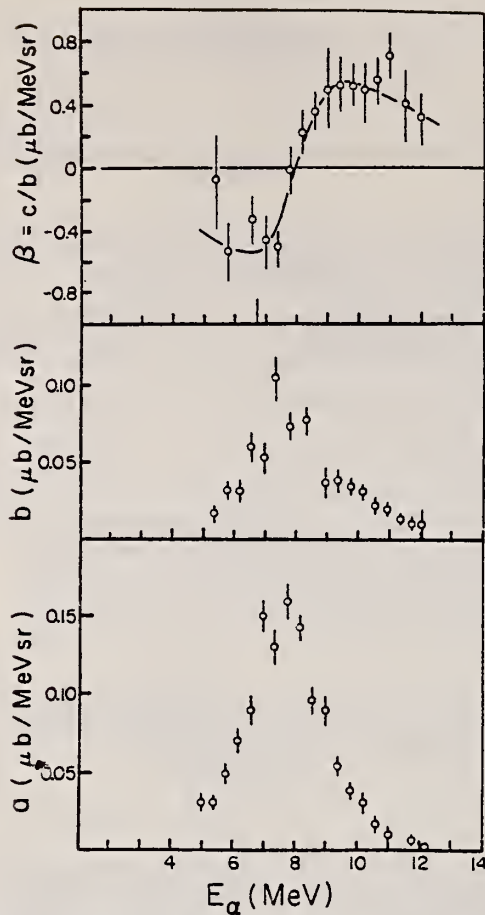


FIG. 4. Angular distribution coefficients ($\mu\text{b}/\text{MeVsr}$) that are found by fitting to Eq. (1). The asymmetry $\beta = c/b$ shows a change in sign that can be associated with resonance interference. The solid line is the result of fitting to an asymmetry defined in the text.

$$\sigma(\theta, E) = a + b \sin^2 \theta + c \sin^2 \theta \cos \theta + d \sin^2 \theta \cos^2 \theta. \quad (1)$$

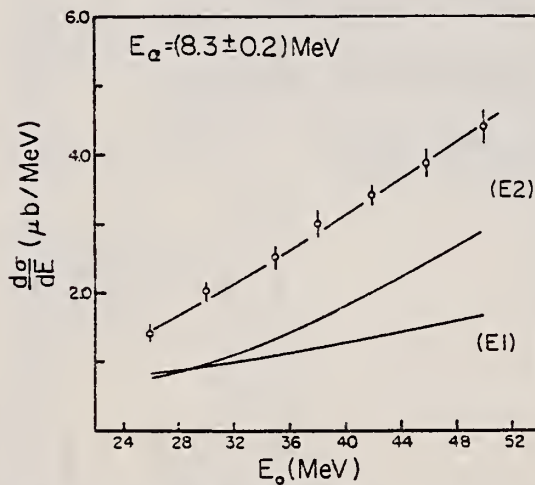


FIG. 5. The cross section $d\sigma/dE$ found by integrating over $d\Omega$ using the angular dependence shown in Fig. 4. These data are analyzed in terms of α particles making transitions to the 2^+ state in ^{52}Cr . The solid lines are the contributions to the cross section from E1 and E2 cross sections by least squares fitting Eq. (3).

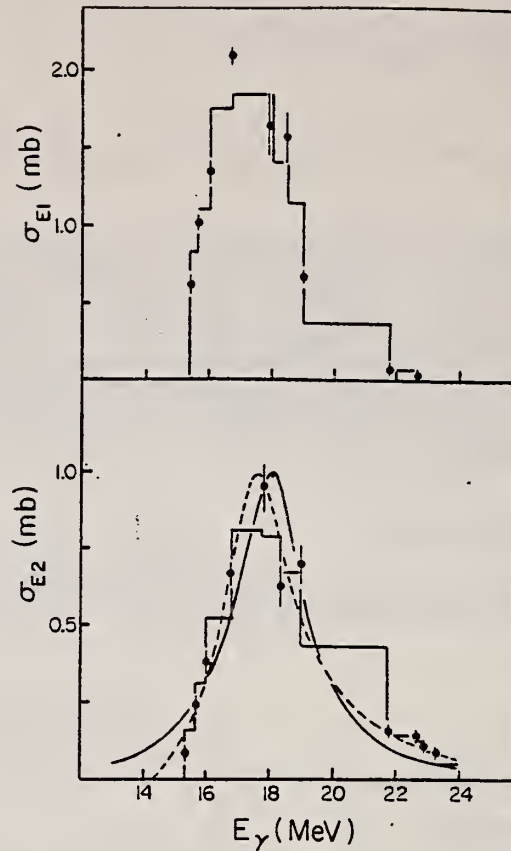


FIG. 8. Total E1 and E2 cross section determined from the isochromat analysis at seven α energies. The dashed line is the Lorentz line shape fit and the solid line is the Breit-Wigner line shape fit. The resonance parameters are summarized in Table I.

TABLE III. Summary of the E1 integrated cross sections for the $^{56}\text{Fe}(e, \alpha)$ reaction and the percentage exhaustion of the sum rule $60NZ/A$.

Analysis	$\int \sigma dE$ (mb MeV)	E_R (MeV)	Γ (MeV)	σ_0 (mb)	% of sum rule
Isochromats	6.41 ± 0.64				
Lorentz					
a	10.51 ± 2.63	16.5 ± 3.1	4.04 ± 0.26	2.19 ± 0.02	0.8 ± 0.1
b	10.44 ± 0.80	17.0 ± 2.5	4.14 ± 0.30	2.02 ± 0.02	1.3 ± 0.3
Breit-Wigner					
a	9.87 ± 3.12	16.7 ± 3.5	4.09 ± 0.3	2.19 ± 0.03	1.2 ± 0.1
b	9.98 ± 2.19	17.1 ± 2.8	4.25 ± 0.23	2.06 ± 0.02	1.2 ± 0.4
					1.2 ± 0.3

^a Fit constrained to the E_2 values of Γ and E_R found from the angular distribution analysis.
^b Unconstrained fit.

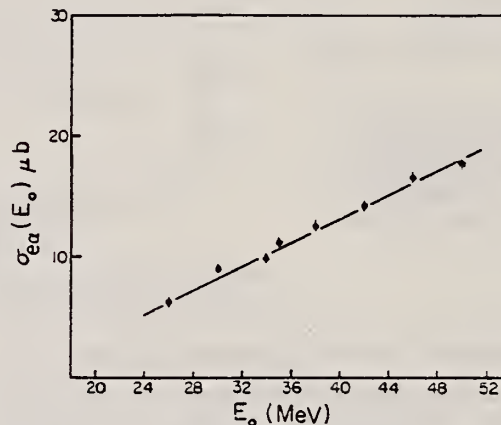


FIG. 9. The total electrodisintegration cross section for the (e, α) channel. The solid line is the result of least square fitting these data with Eq. (1). No appreciable difference was found for Lorentzian and Breit-Wigner line shapes.

REF. T.J. Bowles, R.J. Holt, H.E. Jackson, R.M. Laszewski, R.D. McKeown,
A.M. Nathan, J.R. Specht
Phys. Rev. C24, 1940 (1981)

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		hg
81 Bo 5		

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
G,G	ABX	15-23	D	15-23	NAI-D		90

Quasimonochromatic photons have been used to measure elastic and inelastic photon scattering cross sections in the giant dipole resonance region of ^{52}Cr , Fe, ^{60}Ni , ^{92}Mo , and ^{96}Mo in an experiment in which the elastic and inelastic scattering are resolved. The elastic scattering cross sections show clear evidence for isospin splitting of the giant dipole resonance. The inelastic scattering to low-lying vibrational levels, which is a measure of the coupling between the giant dipole resonance and collective surface vibrations, is in qualitative agreement with the predictions of the dynamic collective model. However, when examined in detail, this model does not provide an adequate description of the scattering data.

NUCLEAR REACTIONS ^{52}Cr , Fe, ^{60}Ni , $^{92,96}\text{Mo}$ (γ, γ'), $14 \leq E_\gamma \leq 22$ MeV; measured E_γ , $E_{\gamma'}$, $d\sigma/d\Omega$ for γ_0, γ_1 . Compared to DCM predictions. Tagged photons.

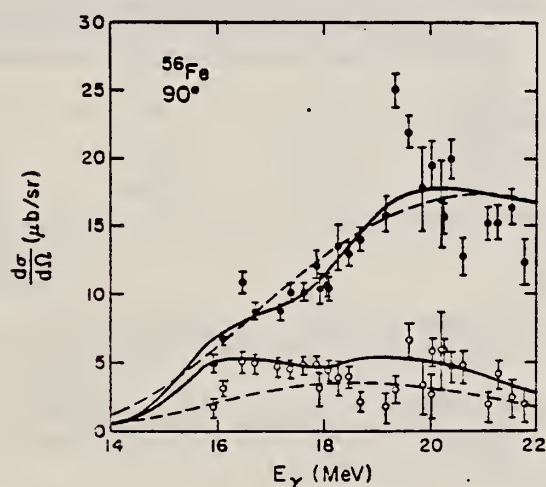


FIG. 7. Elastic (closed circles) and inelastic (open circles) scattering cross sections at $\theta = 90^\circ$ for ^{56}Fe . The error bars represent statistical uncertainties only. The solid (dashed) lines are DCM calculations for the elastic and inelastic cross sections including (not including) the effect of isospin splitting.

ELEM. SYM.	A	Z
Fe	56	26
REF. NO.		
81 Do 2		hg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, P	ABX	10-100	D	16-100	MAG-D		DST
E, A	ABX	7-100	D	16-100	MAG-D		DST

The (e, p) and (e, α) cross sections for ^{56}Fe , ^{59}Co , and ^{64}Zn have been measured in the electron energy range 16–100 MeV. They have been analyzed using the distorted-wave Born approximation $E1$ and $E2$ virtual photon spectra. The $E1$ and $E2$ components in the proton and α channels have been obtained.

NUCLEAR REACTIONS $^{56}\text{Fe}(e, p)$, $^{56}\text{Fe}(e, \alpha)$, $^{59}\text{Co}(e, p)$, $^{59}\text{Co}(e, \alpha)$, $^{64}\text{Zn}(e, p)$, and $^{64}\text{Zn}(e, \alpha)$; measured $\sigma(E_0, E_x, 34^\circ)$, $\sigma(E_0, E_x, 48^\circ)$, $\sigma(E_0, E_x, 62^\circ)$, $\sigma(E_0, E_x, 90^\circ)$, $\sigma(E_0, E_x, 118^\circ)$, $\sigma(E_0, E_x, 132^\circ)$; obtained $\sigma(e, p)$, $\sigma(e, \alpha)$; deduced $\sigma_{\gamma, p}^{E1}(E)$, $\sigma_{\gamma, p}^{E2}(E)$, $\sigma_{\gamma, \alpha}^{E1}(E)$, $\sigma_{\gamma, \alpha}^{E2}(E)$.

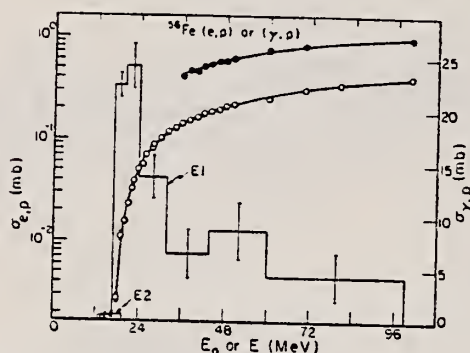


FIG. 3. The measured $\sigma_{e,p}(E_0)$ for ^{56}Fe as a function of total incident electron energy E_0 (open circles). The full circles represent the yield $Y_{e,p}(E_0)$ obtained when a 0.217 g/cm^2 tantalum foil was placed in the electron beam ahead of the target. The smooth curves are the best fits to the data and were obtained by combining the histograms representing the $E1$ and $E2$ (γ, p) cross sections (right-hand scale) in Eqs. (1) and (2) with the $E1$ and $E2$ DWBA virtual photon spectra and by making use of the DBM bremsstrahlung cross section. The size effect correction described in the text has been applied to the virtual photon spectra.

VIRT PHOTON ANAL

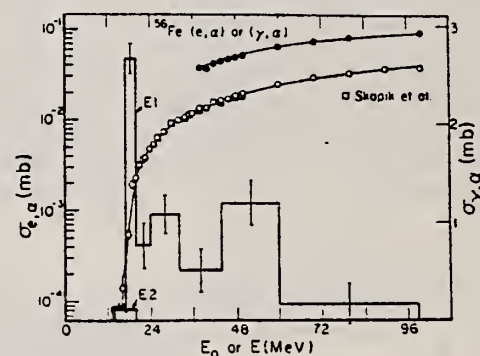


FIG. 6. The $\sigma_{e,a}(E_0)$ for ^{56}Fe . See caption of Fig. 3. The squares represent the data of Ref. 6 and are included to show the good agreement between the two experiments.

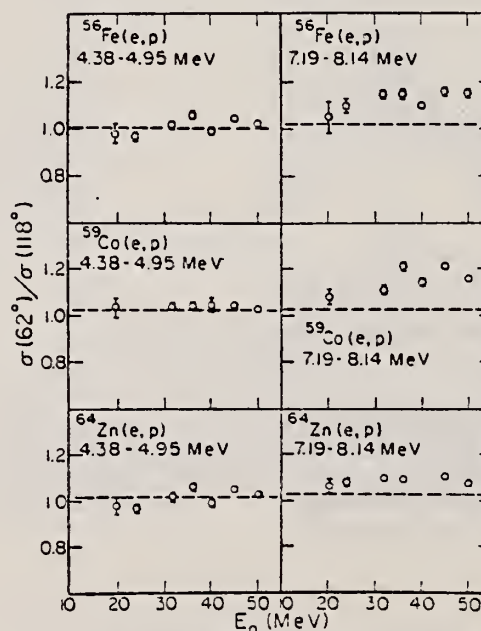


FIG. 9. The ratios of the number of protons observed in the indicated energy bin ΔT_p at 62° to the same number observed at 118° , $\sigma(62^\circ)/\sigma(118^\circ)$, as a function of incident electron energy.

(OVER)

TABLE III. Percentage of the $E2$ sum when only points up to 50 MeV ($E_0=50$ MeV) and when all measured points ($E_0=100$ MeV) are considered in the analysis. The bremsstrahlung cross section used is DBM. $E2$ sum: $0.22Z^2A^{-1/3} \mu\text{b/MeV}$.

Nucleus	Reaction	Without size effect		With size effect	
		$E_0=50$ MeV	$E_0=100$ MeV	$E_0=50$ MeV	$E_0=100$ MeV
^{56}Fe	(e,α)	9 ± 3	3 ± 1	11 ± 3	7 ± 1
	(e,p)	47 ± 30	8 ± 11	61 ± 32	37 ± 15
^{59}Co	(e,α)	7 ± 2	4 ± 1	8 ± 2	5 ± 1
	(e,p)	32 ± 22	4 ± 8	48 ± 24	28 ± 11
^{64}Zn	(e,α)	26 ± 6	12 ± 2	32 ± 6	25 ± 3
	(e,p)	29 ± 43	26 ± 15	56 ± 46	77 ± 21

TABLE IV. Percentage of the $E1$ and $E2$ sums in the α and proton channels. $E1$ sum: $60NZ/A$ MeV mb. $E2$ sum: $0.22Z^2A^{-1/3} \mu\text{b/MeV}$. Integrals to 100 MeV.

Nucleus	Reaction	$E1$		$E2$	
		Schiff	DMB	Schiff	DBM
^{56}Fe	(e,α)	5 ± 1	6 ± 1	10 ± 1	7 ± 1
	(e,p)	67 ± 20	82 ± 19	82 ± 14	37 ± 15
	(e,α)+(e,p)	72 ± 20	88 ± 19	92 ± 14	44 ± 15
^{59}Co	(e,α)	5 ± 1	7 ± 1	8 ± 1	5 ± 1
	(e,p)	52 ± 10	67 ± 12	63 ± 10	28 ± 11
	(e,α)+(e,p)	57 ± 10	74 ± 12	71 ± 10	33 ± 11
^{64}Zn	(e,α)	16 ± 4	18 ± 4	33 ± 3	25 ± 3
	(e,p)	129 ± 28	154 ± 30	137 ± 30	77 ± 21
	(e,α)+(e,p)	145 ± 28	172 ± 30	170 ± 20	102 ± 21

TABLE VI. $E1$ strength integrated up to 30 MeV.

Nucleus	α	$\int_0^{30} \sigma_{\gamma,x}(E) dE$ (MeV mb)			Fraction of $E1$ sum
		p	n	Total	
^{56}Fe	18 ± 3	256 ± 26	735^a	1009	1.21
^{59}Co	15 ± 2	211 ± 22	884^b	1110	1.26
^{64}Zn	66 ± 14	545 ± 75	616^b	1227	1.28

^aReference 13.

^bReference 14.

¹³Y. -W., Lui, P. Bogucki, J. D. Bronson, U. Garg, C. M. Rozsa, and D. H. Youngblood, Phys. Lett. **93B**, 31 (1980).

¹⁴S. Costa, F. Ferrero, S. Ferroni, C. Molino and R. Malvano, Phys. Lett. **11**, 324 (1964). $^{64}\text{Co}2$

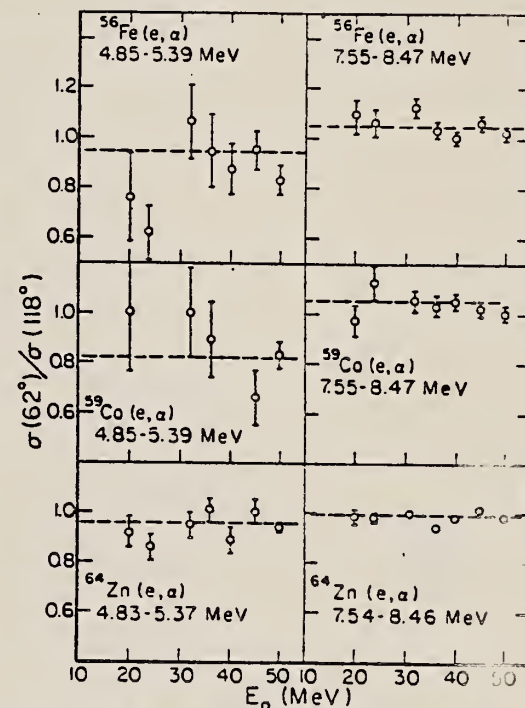


FIG. 10. The ratios of the number of α particles observed in the indicated energy bite ΔT_α at 62° to the same number observed at 118° , $\sigma(62^\circ)/\sigma(118^\circ)$, as a function of incident electron energy.

Fe
A=57

Fe
A=57

Fe
A=57

Method 22 MeV betatron; neutron counting

Ref. No.	
58 To 1	EH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Fe}^{57}(\gamma, n)$	Bremss. 22					$E_{th} = 7.85 \pm 0.13$

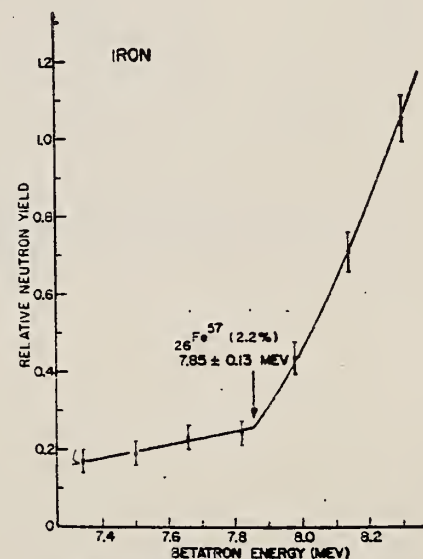


FIG. 2. Photoneutron yield from iron in the betatron-energy range from 7.3 to 8.3 Mev.

Fe	57	26
REF. NO.		NVB

METHOD					REF. NO.		
Betatron; neutron threshold; ion chamber					60 Ge 3		NVB
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NØX	THR	C	THR	BF3-I		4 PI

THRESHOLD

TABLE I. Summary and comparison of neutron separation energies inferred from present threshold measurements with values predicted from mass data and reaction energies. All energies are expressed in the center-of-mass system in Mev.

Reaction	No. runs	Present results	Other results	Method	Reference
$Fe^{57}(\gamma,n)Fe^{56}$	1	7.85 ± 0.13	7.633 ± 0.007	mass data	j
			7.636 ± 0.010	$Fe^{56}(n,\gamma)Fe^{57}$	e
			7.85 ± 0.13	threshold	k

* P. M. Van Patter and W. Whaling, Revs. Modern Phys. 26, 402 (1954); 29, 756 (1957).
† K. S. Quisenberry, T. T. Scolman, and A. O. Nier, Phys. Rev. 104, 461 (1956).
‡ See reference 2.

METHOD

REF. NO.

68 Ok 3

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	ABY	THR-20	C	20	ACT-I		4PI

TABLE I. SUMMARY OF DATA ON (γ ,p) REACTIONS WITH 20 MeV BREMSSTRAHLUNG

Nuclide		S_p (MeV)	Observed γ -ray			Yield determined	
Parent (Natural abundance, %)	Residual (Half-life)		Energy (MeV)	Branching ratio (%)	Type of multipole transition	$\mu\text{Ci}/\text{mg}^a$	Yield/mol-R
^{24}Mg (10.11)	^{24}Na (15 hr)	12.06	1.37	100	E2	1.48×10^{-1}	1.7×10^5
^{28}Si (4.71)	^{28}Al (2.27 min)	12.33	1.78	100	E2	1.91	2.8×10^5
^{30}Si (3.12)	^{30}Al (6.56 min)	13.59	1.28	93.8	E2+M1	6.51×10^{-1}	1.5×10^5
^{40}Ca (2.06)	^{40}K (22.4 hr)	12.17	0.374	85	E2+M1	7.86×10^{-1}	1.3×10^5
^{47}Ti (7.32)	^{47}Sc (84.1 d)	10.47	0.887	100	E2	7.11×10^{-1}	3.1×10^5
^{48}Ti (73.99)	^{48}Sc (3.4 d)	11.44	0.160	100	E2+M1	6.83×10^{-1}	1.2×10^5
^{48}Ti (5.46)	^{48}Sc (1.8 d)	11.35	1.31	100	E2	4.40×10^{-1}	5.8×10^4
^{51}Cr (9.55)	^{51}V (3.8 min)	11.15	1.43	100	E2	5.01×10^{-1}	6.6×10^4
^{55}Fe (2.17)	^{55}Mn (2.58 hr)	10.57	1.81	23.5	E2+M1	8.10×10^{-1}	2.1×10^5
^{74}Ge (36.74)	^{74}Ga (4.8 hr)	10.92	0.295	97	(E2)	3.70×10^{-1}	1.3×10^5
^{77}Se (7.58)	^{77}As (26.5 hr)	9.61	0.559	41	E2	1.48×10^{-1}	1.3×10^5
^{87}Sr (7.02)	^{87}Rb (19 d)	9.41	1.08	9	E2	5.15×10^{-1}	9.9×10^4
^{110}Cd (12.26)	^{110}Ag (3.2 hr)	9.74	1.39	35	E2	1.91×10^{-1}	2.1×10^5
^{117}Sn (7.57)	^{117}In (54 min)	9.58	1.27	84	E2	9.80×10^{-1}	6.9×10^5
^{137}Ba (11.32)	^{137}Cs (13 d)	8.67	0.830	100	E2	1.68×10^{-1}	2.2×10^5
^{199}Hg (16.84)	^{199}Au (2.7 d)	7.27	0.412	100	E2	8.43×10^{-1}	2.2×10^5

a) The value corrected at the end of 1 hr irradiation (9.4×10^4 R/min).

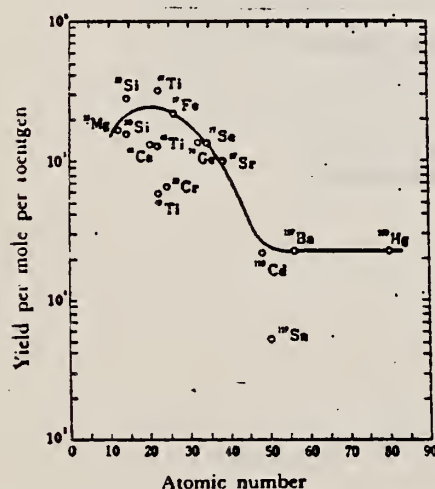


Fig. 2. The yield curve for the (γ ,p) reaction with 20 MeV bremsstrahlung.

METHOD

Page 1 of 3

REF. NO.

71 Ba 2

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	7-12	C	8-12	TOF-D		135
		(7.6-11.5)					

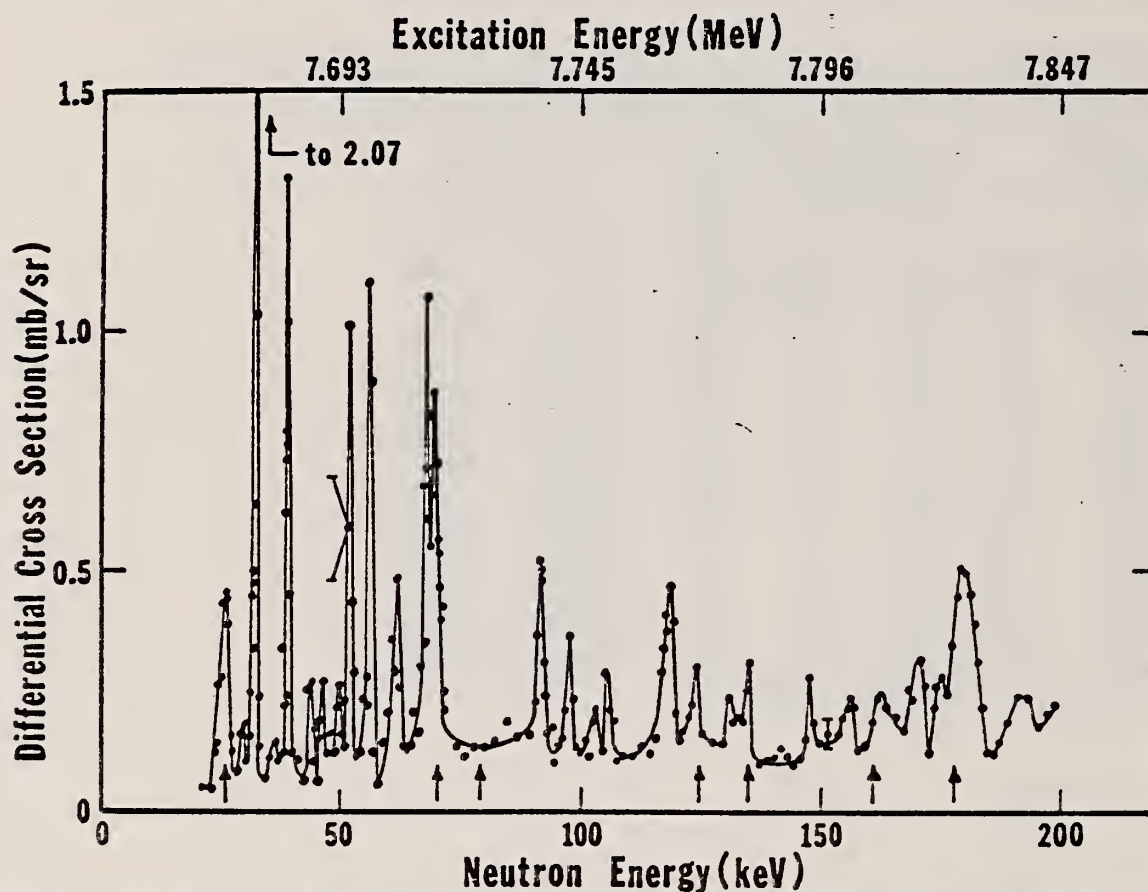


FIG. 9. The 135° differential threshold photoneutron cross section for ^{56}Fe , at low energies (see caption to Fig. 4). The arrows below the data indicate the positions of $J^\pi = \frac{1}{2}^+$ states obtained from neutron total cross-section measurements on ^{56}Fe . The 26-keV peak is asymmetric.

TABLE VI. Resonance parameters for $^{56,57}\text{Fe}$ and $^{52,53}\text{Cr}$. For all resonances, the area under the peak in the 135° differential cross section is multiplied by 4π to yield approximate values for $g_\gamma \Gamma_{\gamma 0} \Gamma_n / \Gamma \approx g_\gamma \Gamma_{\gamma 0}$. For those resonances where J^π is known, the differential area is multiplied by the appropriate factor F from Table I to obtain $\Gamma_{\gamma 0}$. E_L is the laboratory neutron energy for the (γ, n) reaction and E_n is the corresponding laboratory neutron energy for a neutron-induced reaction. Column 5 labels the peak as a ground-state (GS) or excited-state (ES) transition as determined in this work alone. Clearly, if a peak is seen in a neutron-induced reaction (columns 9-11), it must be GS.

Nucleus	E_L (keV)	E_{ex} (MeV)	$g_\gamma \Gamma_{\gamma 0} \Gamma_n / \Gamma$ (eV)	GS or ES	J^π	$\Gamma_{\gamma 0}$ (eV)	E_n (keV) (This work)	E_n (keV) from neutron- induced reactions (Ref. a) (Ref. b) (Ref. c)		
^{57}Fe	26.0	7.669	0.084		$\frac{1}{2}^+$	0.17	27.7	28	27.7	
	32.3	7.675	0.11				34.3		34.1	
	38.7	7.682	0.055				41.0			
	51.8	7.695	0.080				54.7			
	56.2	7.699	0.12				59.4		59.0	
	61.5	7.705	0.067				64.9		63.1	
	68.2	7.712	0.10				71.8			
	69.1	7.713	0.12		$\frac{1}{2}^+$	0.24	72.8	74	72.6	
	91.6	7.736	0.069				96.3		95.9	
	97.7	7.743	0.031				102.7		102	
	106	7.751	0.022				111		112	
	119	7.764	0.094	GS			125			
	124	7.769	0.028		$\frac{1}{2}^+$	0.056	130	131	129	
	135	7.781	0.036		$\frac{1}{2}^+$	0.072	141	142		
	148	7.794	0.027				155			
	156	7.802	0.044				163	164		
	162	7.808	0.059		$\frac{1}{2}^+$	0.12	170	169		
	171	7.817	0.072				179			
	179	7.826	0.21	GS	$\frac{1}{2}^+$	0.42	187	187		
	192	7.839	0.050				201			
	212	7.859	0.36	GS	$\frac{1}{2}^+$	0.72	222	220		
	223	7.871	0.40				233			
	232	7.880	0.26	GS	$\frac{1}{2}^+$	0.52	243	244		
	245	7.893	0.072				256			
	259	7.907	0.11		$\frac{1}{2}^+$	0.22	271	273		
	274	7.923	0.15				286			
	299	7.948	0.32		$\frac{1}{2}^+$	0.64	312	315		
	330	7.980	0.32				345			
	393	8.045	0.31				410	406		

^aSee Ref. 17.

^bSee R. W. Hockenbury, Z. M. Bartolome, J. R. Tatarczuk, W. R. Moyer, and R. C. Block, Phys. Rev. **178**, 1746 (1969).

^cSee Ref. 19.

¹⁷C.D. Bowman, E.G. Bilpuch, and H.W. Newson, Ann. Phys. (N.Y.) **17**, 319 (1962).

^bSee R.W. Hockenbury, Z.M. Bartolome, J.R. Tatarczuk, W.R. Moyer, and R.C. Block, Phys. Rev. **178**, 1746 (1969).

¹⁹R.G. Steiglitz, Ph.D. thesis, Rensselaer Polytechnic Institute, 1970 (unpub.)

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

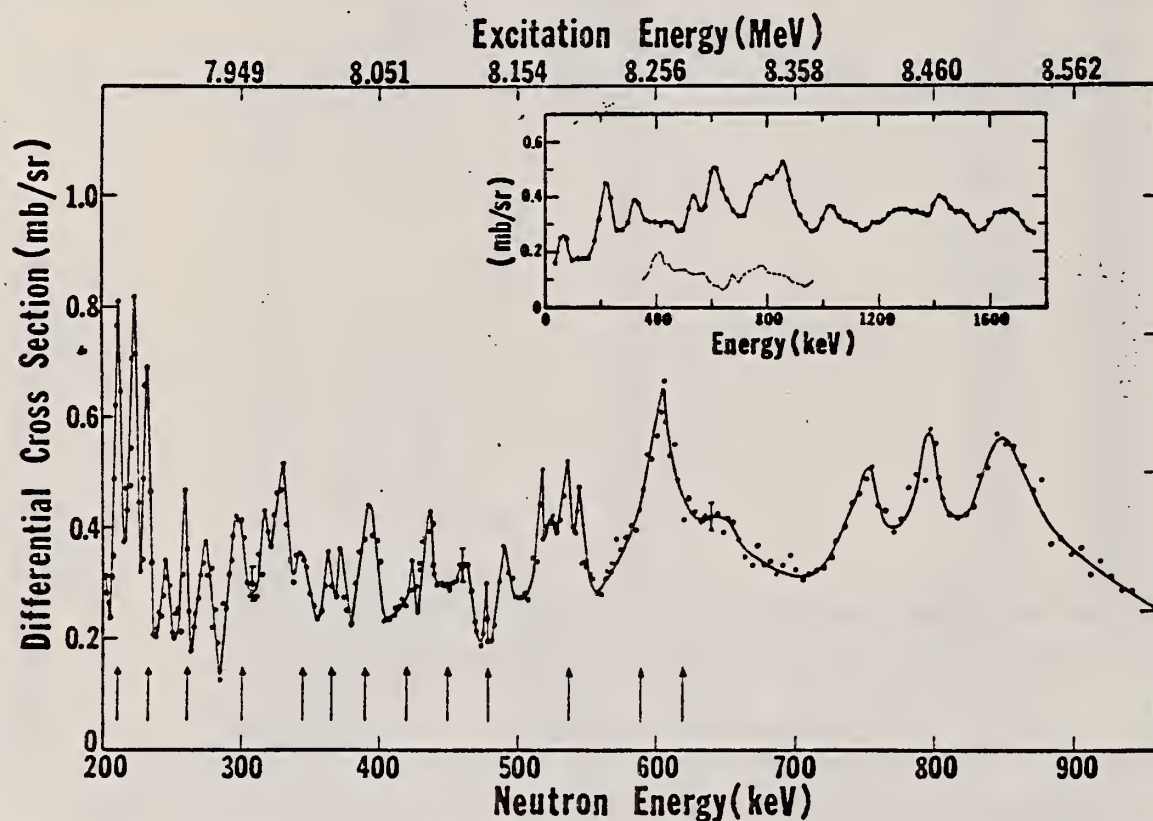


FIG. 10. The 135° differential threshold photonuclear cross section for ^{57}Fe , at high energies (see caption to Fig. 4). The arrows below the data indicate the positions of $J^\pi = \frac{1}{2}^+$ states obtained from neutron total cross-section measurements on ^{56}Fe . The dashed curve in the inset is the smoothed total cross section for ^{56}Fe .

ELEM. SYM.	A	Z
Fe	57	26
REF. NO.		
71 Ja 1		hmg

METHOD					REF. NO.		
					71 Ja 1	hmg	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	RLX	7-8	C	7-8	TOF-D		DST
		(7.6-8.45)		(7.6-8.45)			

No evidence found near threshold for doorway states.

TABLE III. Energies and parameters for resonances in the reaction $^{57}\text{Fe}(\gamma, n)$. The $\approx 20\%$ error in the quantity $\Gamma_0\Gamma_n/\Gamma$ for all resonances is due mainly to the uncertainty in the absolute normalization of the data. The energies given in column 2 are calculated from those of column 1 by applying a correction for recoil effects. For unassigned levels, column 4 gives $g\Gamma_0\Gamma_n/\Gamma$.

$E_n(\pi, \gamma)$ References 19, 22 (keV)	$E_n(\gamma, \pi)$ at $\theta = 90^\circ$ Calc. Obs. (keV) (keV)		$\Gamma_\gamma \Gamma_\pi / \Gamma$ (eV)
$J = \frac{1}{2}^+$			
27.9	26.9	26.7	0.112
74	71.4	70.2	0.082
83.7	80.8	...	...
123.5	119.2	118.4	0.119
130	125.5	125.1	0.105
141	136	136	0.068
169	163	163	0.066
188	181	181	0.423
220	212	212	0.683
			Total 1.658
$J = \frac{1}{2}^-$			
34.1	32.9	32.9	0.180
59	56.9	56.9	0.221
...	...	216	0.130
...	...	278	0.208
			Total 0.739
$J = \frac{3}{2}^-$			
...	...	224	0.364
...	...	235	0.382
...	...	270	0.090
			Total 0.836
Unassigned levels			
...	...	92.6	0.045
...	...	98.7	0.042
...	...	167	0.032
...	...	247	0.030
...	...	260	0.016
			Total 0.195

TABLE IV. Angular momentum assignments for resonances in the reaction $^{57}\text{Fe}(\gamma, n)$.

$E_n(\gamma, n)$ (keV)	$\frac{d\sigma(90^\circ)/d\Omega}{d\sigma(135^\circ)/d\Omega}$	J^π	$E_n(\gamma, n)$ (keV)	$\frac{d\sigma(90^\circ)/d\Omega}{d\sigma(135^\circ)/d\Omega}$	J^π
26.7	s wave	$\frac{1}{2}^+$	181	s wave	$\frac{1}{2}^+$
32.9	1.10 ± 0.08	$\frac{1}{2}^-$	212	s wave	$\frac{1}{2}^+$
56.9	1.08 ± 0.09	$\frac{1}{2}^-$	216	0.90 ± 0.10	$\frac{1}{2}^-$
70.2	s wave, other	$\frac{1}{2}^+, ?$	224	1.32 ± 0.04	$\frac{1}{2}^-$
118.4	s wave	$\frac{1}{2}^+$	235	1.43 ± 0.04	$\frac{1}{2}^-$
125.1	s wave	$\frac{1}{2}^+$	270	1.36 ± 0.09	$\frac{1}{2}^-$
136.	s wave	$\frac{1}{2}^+$	278	0.99 ± 0.07	$\frac{1}{2}^-$
163.	s wave	$\frac{1}{2}^+$			

(over)

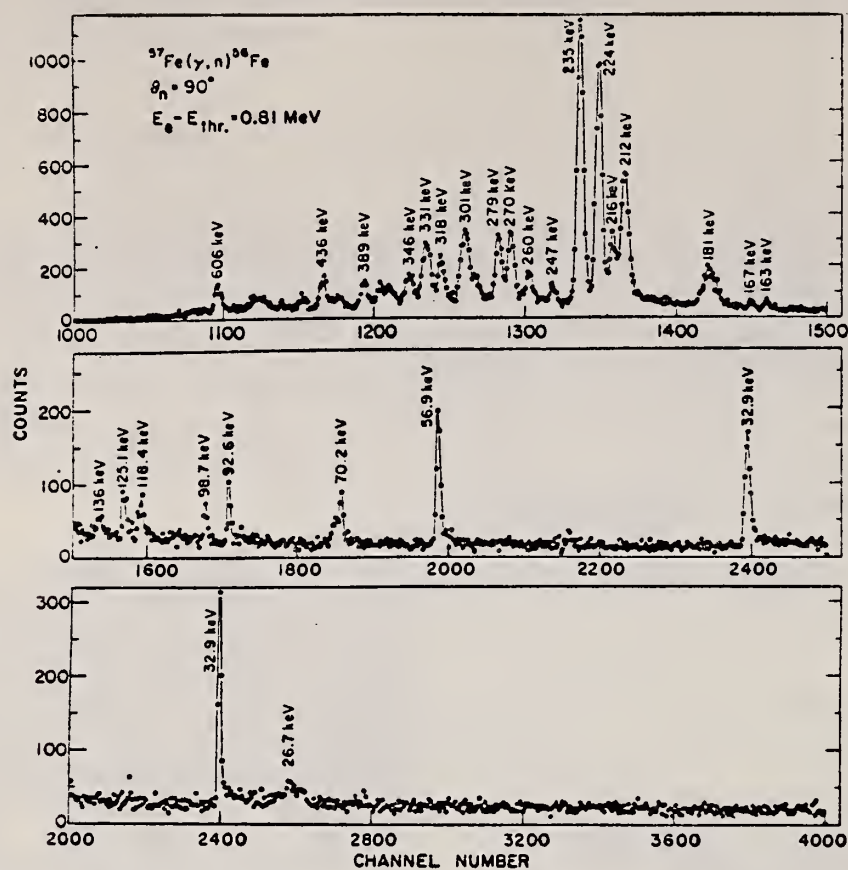


FIG. 6. Photoneutron time-of-flight spectrum for $^{57}\text{Fe}(\gamma, n)$. The flight path was 9 m. Each point in the center section represents the sum of two adjacent channels; in the lower section they represent sums of four adjacent channels.

TABLE VII. Integrated yields and reduced widths for electric and magnetic dipole radiation. Integrated yields are given for all resonances observed, but reduced widths for magnetic dipole transitions are calculated only from yields for p -wave levels above 100-keV neutron energy (see discussion in Sec. IV). The number of resonance widths used to obtain each $\bar{\Gamma}$ is given by n . The errors given were calculated by assuming that the individual Γ_γ 's follow a Porter-Thomas distribution.

Target	J^π	$\sum g \Gamma_\gamma \Gamma_n / \Gamma$ (eV)	$\sum \Gamma_\gamma \Gamma_n / \Gamma$ (eV)	n	$10^3 \times$ reduced width Individual average
^{53}Cr	$\frac{1}{2}^+$	0.97	3.88	7	$\bar{\kappa}_{E1} = 1.7^{+1.1}_{-0.5}$
	$\frac{1}{2}^-$	1.27	5.06	6	$\bar{\kappa}_{M1} = 41$
	$\frac{3}{2}^-$	0.86	1.71	10	$\bar{\kappa}_{M1} = 16$
^{57}Fe	$\frac{1}{2}^+$	0.83	1.66	8	$\bar{\kappa}_{E1} = 0.86^{+0.8}_{-0.3}$
	$\frac{1}{2}^-$	0.37	0.74	4	$\bar{\kappa}_{M1} = 9$
	$\frac{3}{2}^-$	0.84	0.84	3	$\bar{\kappa}_{M1} = 10$
^{61}Ni	$\frac{1}{2}^+$	0.37	1.48	11	$\bar{\kappa}_{E1} = 0.96^{+0.42}_{-0.19}$
	$\frac{1}{2}^-$	0.41	1.65	5	$\bar{\kappa}_{M1} = 27$
	$\frac{3}{2}^-$	0.54	1.07	3	$\bar{\kappa}_{M1} = 12$

REF.

H. E. Jackson and E. N. Strait

Statistical Properties of Nuclei, ed. J. B. Garg, Plenum Publishing Corporation, New York (1971) p. 601

ELEM. SYM.

A

Z

Fe

57

26

METHOD

REF. NO.

71 Ja 2

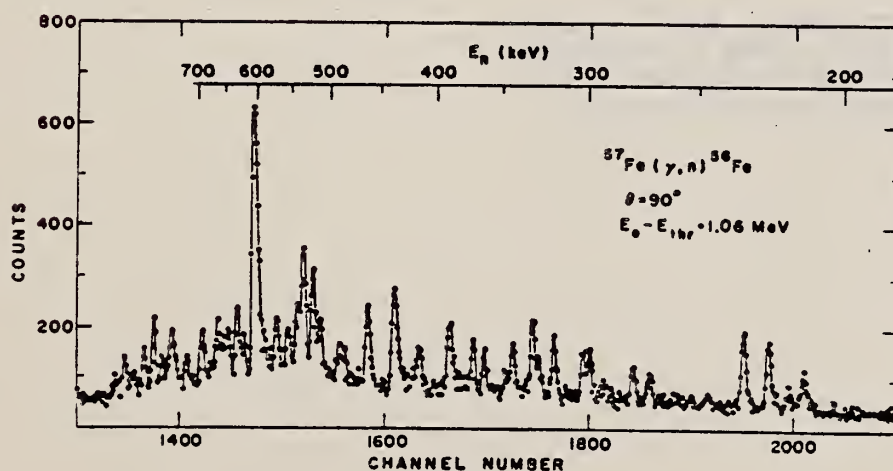
egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	RLX	8-9	C	8	TOF-D		DST
		(7.6-8.45)		(8.45)			

7.6-8.4 MEV, G-WIDTH

TABLE I. Angular-momentum assignments for resonances in the reaction $^{57}\text{Fe}(\gamma, n)$.

E_n (keV)	$\frac{d\sigma(90^\circ)/d\Omega}{d\sigma(135^\circ)/d\Omega}$	J^π	E_n (keV)	$\frac{d\sigma(90^\circ)/d\Omega}{d\sigma(135^\circ)/d\Omega}$	J^π
26.7	s-wave	$\frac{1}{2}^+$	181.	1.05 ± 0.07	$\frac{1}{2}^+$
32.9	1.10 ± 0.08	$\frac{1}{2}^-$	212	1.00 ± 0.03	$\frac{1}{2}^+$
56.9	1.08 ± 0.09	$\frac{1}{2}^-$	216	0.90 ± 0.10	$\frac{1}{2}^-$
70.2	s-wave, other	$\frac{1}{2}^+, ?$	224	1.32 ± 0.04	$\frac{3}{2}^-$
118.4	s-wave	$\frac{1}{2}^+$	235	1.43 ± 0.04	$\frac{3}{2}^-$
125.1	s-wave	$\frac{1}{2}^+$	270	1.36 ± 0.09	$\frac{3}{2}^-$
136	s-wave	$\frac{1}{2}^+$	278	0.99 ± 0.07	$\frac{1}{2}^-$
163	s-wave	$\frac{1}{2}^+$			

Fig. 4. Photoneutron time-of-flight spectrum for $^{57}\text{Fe}(\gamma, n)$ as observed with a proton-recoil neutron detector.

(over)

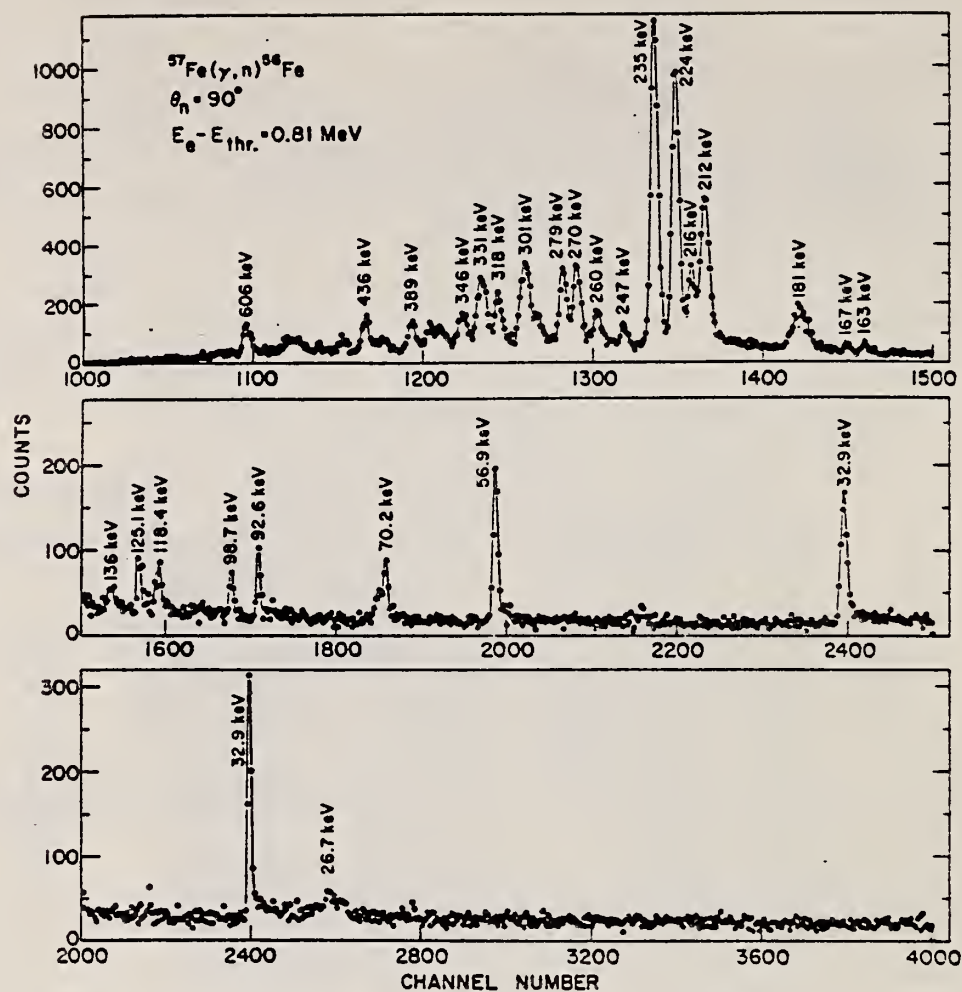


Fig. 2. Photoneutron time-of-flight spectrum for $^{57}\text{Fe}(\gamma, n)$. Points in the center section are sums of two adjacent channels; in the lower section they are sums of four adjacent channels. The data were taken with ^6Li glass detectors.

Fe
A=58

Fe
A=58

Fe
A=58

ELEM. SYM.	A	Z
Fe	58	26
REF. NO.		hmg
72 Li 3		

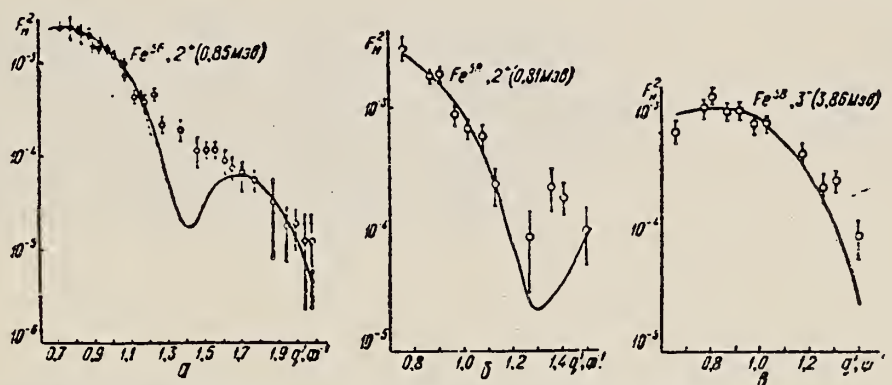
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E, E/	FMF	1, 4	D	150, 225	MAG-D		DST

Таблица 1

B(EL) L EV .81, 3.86

Параметры фермиевского распределения плотности заряда
(с—радиус полусфера плотности, t—диффузность ядра)

Ядро	c, ф	t, ф
Fe ⁵⁴	4.012 ± 0.007	2.346 ± 0.011
Fe ⁵⁶	3.971 ± 0.013	2.608 ± 0.020
Fe ⁵⁸	4.027 ± 0.019	2.530 ± 0.031
Ni ⁶²	4.149 ± 0.011	2.506 ± 0.016



Формфакторы E2- и E3-переходов в ядрах Fe⁵⁴ (а) и Fe⁵⁸ (б, в). Сплошные кривые — расчет по вибраторной модели в высокочастотном приближении: ⊗ — 150 Мэв; ○ — 225 Мэв, Δ — данные работы [6]; пунктирная кривая — расчет в борновском приближении [6].

Таблица 2

Ядро	E _λ , Мэв	J _π	Данные настоящей работы	Данные других работ		Литература
			B(EL) ↑, eλ ₀ 2λ	B(EL) ↑, eλ ₀ 2λ	Тип эксперимента и метод определения	
Fe ⁵⁴	1.4	2 ⁺	531.9 ± 32.4	533	(ee'), борновское приближение	[6]
	4.85	3 ⁻	4563 ± 410	4390		
Fe ⁵⁶	0.85	2 ⁺	678.1 ± 47.5	720	(ee'), борновское приближение искаженные волны борновское приближение кулоновское возбуждение	[7] [18]
				1250 ± 270		
				1240		
Fe ⁵⁸	0.81	2 ⁺	943.2 ± 79			
	3.86	3 ⁻	13880 ± 1260			
Ni ⁶²	1.17	2 ⁺	618.6 ± 42.1	877 ± 11	(ee'), искаженные волны	[9]
	3.75	3 ⁻	14359 ± 962	20100 ± 540		

Co
A=55

COBALT
Z=27

Ores containing cobalt have been used since antiquity as pigments, but without knowledge of the source of the color. The word cobalt is from the Greek word "*cobalos*" meaning mine. Its German form signified a mischievous spirit (gnomes or goblins) and was used by the German miners in Saxony to designate certain ores which injured their hands and feet. These ores were later found to contain arsenical cobalt.

Co
A=55

Co
A=55

REF.

D.J. Martin, J.R. Leslie, W. McLatchie, C.F. Monahan, and
L.E. Carlson
Nucl. Phys. A187, 337 (1972)

ELEM. SYM.	A	Z
Co	55	27
REF. NO.		egf
72 Ma 2		

METHOD					REF. NO.	
					72 Ma 2	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
P,G	LFT	7	D	2	SCD-D	

TABLE I

Summary of γ -ray angular distribution coefficients, multipole mixing ratios and spin hypotheses for the $E_{\gamma} = 1803$ keV resonance

J-PI

Transition $E_i - E_f$ (MeV)	A_0	a_2	a_4	Spin sequence $J_i \rightarrow J_f$	Mixing ratio δ
6.83 \rightarrow 0	100 ± 3	-0.30 ± 0.06	0.02 ± 0.06	$\frac{1}{2} \rightarrow \frac{1}{2}$	$-0.09^{+0.02}_{-0.01}$
6.83 \rightarrow 2.16	8 ± 1	0.34 ± 0.19	-0.02 ± 0.14	$\frac{3}{2} \rightarrow \frac{1}{2}$	$0.36^{+0.16}_{-0.08}$
6.83 \rightarrow 2.56	4 ± 1	-0.19 ± 0.25	0.24 ± 0.25	$\frac{3}{2} \rightarrow \frac{1}{2}$	$0.30^{+0.23}_{-0.20}$
6.83 \rightarrow 2.92	8 ± 1	-0.32 ± 0.10	0.11 ± 0.17	$\frac{1}{2} \rightarrow \frac{1}{2}$	$-0.09^{+0.17}_{-0.18}$
				$\frac{3}{2} \rightarrow \frac{1}{2}$	$-0.36^{+0.18}_{-0.15}$
6.83 \rightarrow 3.32	23 ± 2	-0.62 ± 0.10	0.00 ± 0.10	$\frac{1}{2} \rightarrow \frac{1}{2}$	$0.08^{+0.04}_{-0.04}$
				$\frac{3}{2} \rightarrow \frac{1}{2}$	$1.32^{+1.00}_{-0.35}$
6.83 \rightarrow 3.73	19 ± 2	-0.08 ± 0.13	-0.07 ± 0.13	$\frac{3}{2} \rightarrow \frac{1}{2}$	$0.36^{+0.04}_{-0.06}$
				$\frac{1}{2} \rightarrow \frac{1}{2}$	$0.00^{+0.07}_{-0.08}$
				$\frac{3}{2} \rightarrow \frac{1}{2}$	$-0.17^{+0.05}_{-0.15}$
6.83 \rightarrow 4.16	8 ± 1	-0.65 ± 0.20	-0.03 ± 0.18	$\frac{1}{2} \rightarrow \frac{1}{2}$	$0.09^{+0.12}_{-0.10}$
				$\frac{3}{2} \rightarrow \frac{1}{2}$	$1.19^{+0.95}_{-0.35}$
6.83 \rightarrow 4.72	7 ± 1	0.26 ± 0.17	0.00 ± 0.15	$\frac{1}{2} \rightarrow \frac{1}{2}$	$0.09^{+0.09}_{-0.10}$

TABLE 3

Gamma-ray transition probabilities for the strong transitions observed from the $E_{\gamma} = 1803$ keV resonance

Transition $E_i - E_f$ (MeV)	E_{γ} (MeV)	I_{γ}^* (nV)	Spin sequence $J_i \rightarrow J_f$	$B(M1)$ (W.u. $\times 10^3$)	$B(E2)$ (W.u.)
6.83 \rightarrow 2.92	3.91	20 ± 4	$\frac{1}{2} \rightarrow \frac{1}{2}$	16 ± 3	
6.83 \rightarrow 3.32	3.51	57 ± 8	$\frac{1}{2} \rightarrow \frac{1}{2}$	63 ± 8	
			$\frac{3}{2} \rightarrow \frac{1}{2}$	23^{+9}_{-10}	6 ± 1
6.83 \rightarrow 3.73	3.11	48 ± 8	$\frac{1}{2} \rightarrow \frac{1}{2}$	67 ± 12	
			$\frac{3}{2} \rightarrow \frac{1}{2}$	74 ± 12	
			$\frac{1}{2} \rightarrow \frac{1}{2}$		16 ± 3
6.83 \rightarrow 4.16	2.67	20 ± 4	$\frac{1}{2} \rightarrow \frac{1}{2}$	51 ± 10	
			$\frac{3}{2} \rightarrow \frac{1}{2}$	23 ± 6	8 ± 1
6.83 \rightarrow 4.72	2.11	11 ± 3	$\frac{1}{2} \rightarrow \frac{1}{2}$	59 ± 16	1 ± 1

TABLE 4
Gamma-ray transition probabilities for the strong transitions observed from the $E_p = 1887$ keV resonance

Transition $E_i \rightarrow E_f$ (MeV)	E_γ (MeV)	Γ_γ (meV)	Spin sequence $J_i \rightarrow J_f$	$B(M1)$ (W.u. $\times 10^3$)	$B(E2)$ (W.u.)
$6.92 \rightarrow 0$	6.92	19 ± 4	$\frac{5}{2} \rightarrow \frac{1}{2}$	2.7 ± 0.5	
$6.92 \rightarrow 2.56$	4.35	22 ± 5	$\frac{13}{2} \rightarrow \frac{5}{2}$	13 ± 4	
$6.92 \rightarrow 2.92$	3.99	4 ± 2	$\frac{7}{2} \rightarrow \frac{3}{2}$	2.0 ± 1.0	0.08 ± 0.06
$6.92 \rightarrow 3.73$	3.19	12 ± 3	$\frac{15}{2} \rightarrow \frac{7}{2}$	17 ± 4	
			$\frac{7}{2} \rightarrow \frac{3}{2}$	14 ± 4	0.5 ± 0.4
			$\frac{9}{2} \rightarrow \frac{5}{2}$	9 ± 3	1.5 ± 0.8
$6.92 \rightarrow 3.86$	3.06	11 ± 3	$\frac{13}{2} \rightarrow \frac{7}{2}$	17 ± 4	
			$\frac{11}{2} \rightarrow \frac{5}{2}$	16 ± 4	0.5 ± 0.3
			$\frac{15}{2} \rightarrow \frac{7}{2}$	17 ± 4	
$6.92 \rightarrow 4.18$	2.74	7 ± 2	$\frac{13}{2} \rightarrow \frac{7}{2}$	17 ± 4	
			$\frac{15}{2} \rightarrow \frac{9}{2}$	12 ± 3	1.3 ± 0.3
$6.92 \rightarrow 4.72$	2.19	14 ± 2	$\frac{13}{2} \rightarrow \frac{7}{2}$	65 ± 9	0.2 ± 0.1

J.V. Maher, L. Meyer-Schutzmeister, E.L. Sprenkel-Segel,
D. von Ehrenstein, R.J. Nemanich, G.C. Kiang, J.F. Tonn, R.E. Segel
Phys. Rev. C9, 1440 (1974)

ELEM. SYM.	A	Z
Co	55	27
REF. NO.		
74 Ma 1		hmg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	ABX	9- 22	D	4- 17	NAI-D		DST

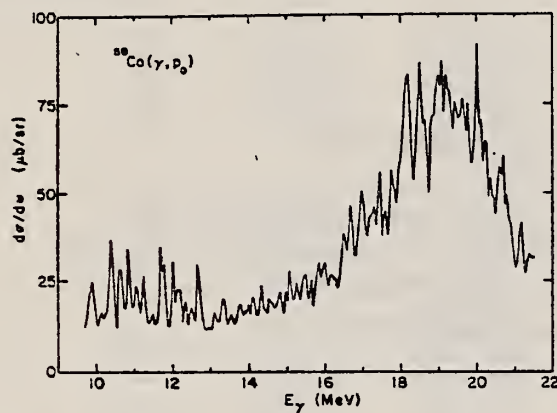


FIG. 3. Yield curve at 90° for the $^{55}\text{Co}(\gamma, p)^{54}\text{Fe}$ reaction obtained by applying detailed balance to the $^{54}\text{Fe}(p, \gamma)$ measured cross sections.

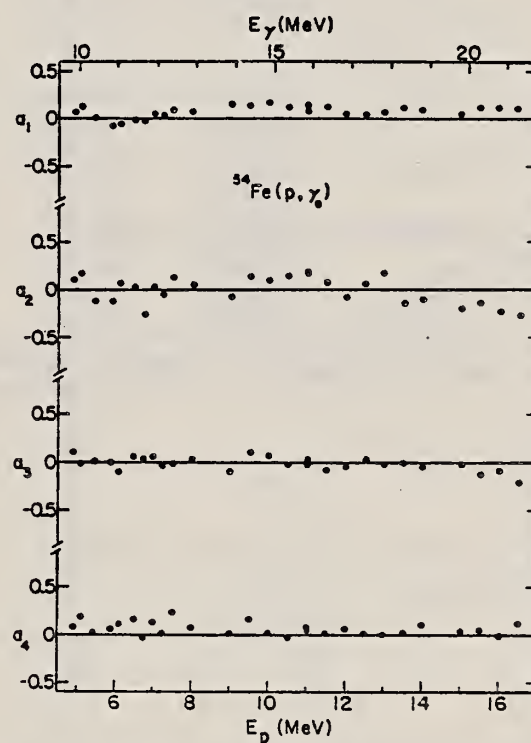


FIG. 7. Coefficients obtained when the $^{54}\text{Fe}(p, \gamma)$ angular distributions are expressed as a sum of Legendre polynomials.

REF.

C.P. Cameron, N.R. Roberson, D.G. Rickel, R.D. Ledford,
H.R. Weller, R.A. Blue, D.R. Tilley
Phys. Rev. C14, 553 (1976)

ELEM. SYM.

A

Z

Co

55

27

METHOD

REF. NO.

76 Ca 4

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$ P,G	ABX	14- 22	D	8- 15	NAI-D		DST

POLARIZED PROTONS

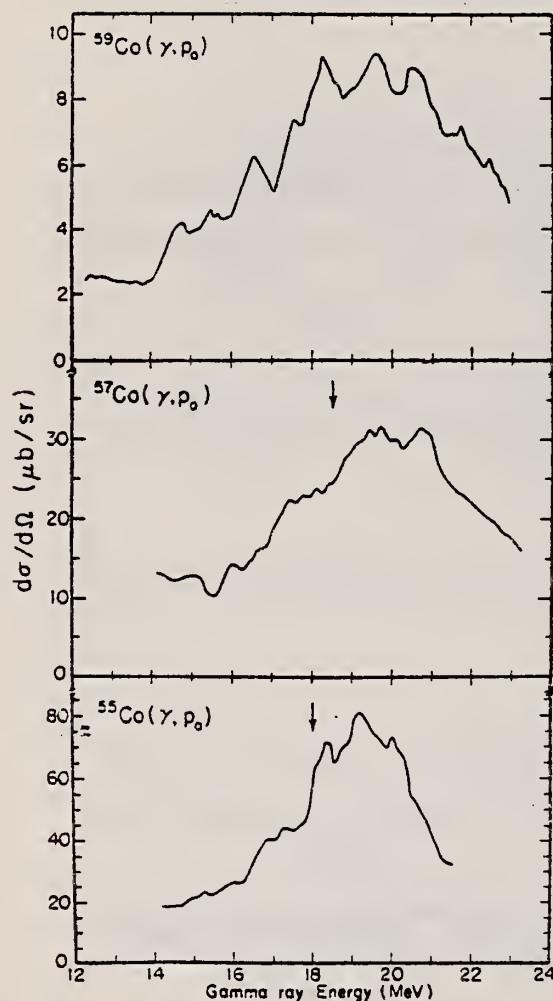


FIG. 3. The 90° yield curves for the $^{54,56,58}\text{Fe}(p, \gamma)$ reactions after averaging over a 500 keV interval. The arrows indicate the energy of the splitting between the T_1 and T_2 components of the GDR as suggested in Ref. 1.

$$\sigma(\theta) = a_0 \left[1 + \sum_i \frac{a_i}{a_0} Q_i P_i(\cos\theta) \right],$$

$$A(\theta) = \frac{(N_+ - N_-)}{(N_+ + N_-)} \frac{1}{P}. \quad (\text{Where } N_+ \text{ and } N_- \text{ are counts spin up and counts spin down.})$$

$$A(\theta)\sigma(\theta)/a_0 = \sum_i b_i Q_i P_i(\cos\theta).$$

- ¹ J.V. Maher, L. Meyer-Schutzmeister, E.L. Sprenkel-Segel, D. von Ehrenstein, R.J. Nemanich, G.C. Kiang, J.F. Tonn, and R.E. Segel, Phys. C9, 1440 (1974).

(over)

TABLE III. The a and b coefficients obtained from least square fits to the data as described in the text. Higher order coefficients are given only when the criterion of normalized χ^2 justified the use of higher order terms.

E_p (MeV)	a_1/a_0	a_2/a_0	a_3/a_0	b_1	b_2	b_3
$^{54}\text{Fe}(\bar{p}, \gamma)^{55}\text{Co}$						
8.0	0.26 ± 0.06	0.11 ± 0.11		-0.03 ± 0.05	0.00 ± 0.04	-0.02 ± 0.04
9.0	0.20 ± 0.05	0.09 ± 0.10		-0.07 ± 0.04		
10.0	0.25 ± 0.04	0.03 ± 0.07		0.02 ± 0.03	-0.09 ± 0.02	
11.0	0.10 ± 0.03	0.24 ± 0.05		0.03 ± 0.02	-0.07 ± 0.02	
12.1	0.27 ± 0.05	0.18 ± 0.04	0.18 ± 0.07	0.01 ± 0.01	-0.12 ± 0.01	
13.0	0.01 ± 0.03	-0.09 ± 0.05		0.03 ± 0.02	-0.15 ± 0.01	
14.0	0.07 ± 0.03	0.0 ± 0.05		-0.02 ± 0.02	-0.16 ± 0.02	-0.02 ± 0.02
15.0	0.18 ± 0.03	-0.12 ± 0.06		0.01 ± 0.02	-0.20 ± 0.02	-0.03 ± 0.02
$^{56}\text{Fe}(\bar{p}, \gamma)^{57}\text{Co}$						
8.0	0.27 ± 0.06	0.03 ± 0.12		0.08 ± 0.05	-0.01 ± 0.04	
9.0	0.07 ± 0.04	-0.04 ± 0.08		-0.05 ± 0.03	-0.06 ± 0.02	-0.03 ± 0.02
10.0	0.08 ± 0.03	0.24 ± 0.06		0.05 ± 0.02	-0.08 ± 0.02	-0.02 ± 0.02
11.5	0.03 ± 0.03	0.20 ± 0.05		-0.08 ± 0.03	-0.09 ± 0.02	
13.0	0.14 ± 0.03	0.15 ± 0.05		0.02 ± 0.02	-0.22 ± 0.02	-0.03 ± 0.02
14.5	0.14 ± 0.04	-0.34 ± 0.08		0.10 ± 0.03	-0.21 ± 0.02	-0.04 ± 0.02
$^{58}\text{Fe}(\bar{p}, \gamma)^{57}\text{Co}$						
7.6	0.19 ± 0.05	0.19 ± 0.09		0.04 ± 0.03	-0.02 ± 0.03	
9.2	0.12 ± 0.04	0.28 ± 0.07		0.01 ± 0.03	-0.11 ± 0.02	
9.6	0.04 ± 0.04	0.26 ± 0.07		0.06 ± 0.02	-0.17 ± 0.02	
10.5	0.12 ± 0.04	0.15 ± 0.06		0.04 ± 0.02	-0.17 ± 0.02	0.04 ± 0.02
11.2	0.16 ± 0.04	0.09 ± 0.06		0.08 ± 0.02	-0.18 ± 0.02	
11.9	0.18 ± 0.05	-0.14 ± 0.09		0.03 ± 0.03	-0.20 ± 0.03	-0.04 ± 0.03
12.7	0.13 ± 0.05	-0.25 ± 0.09		0.07 ± 0.03	-0.23 ± 0.02	
13.5 ^a	0.08 ± 0.09	-0.28 ± 0.09	0.00 ± 0.14	0.06 ± 0.03	-0.22 ± 0.02	
14.0 ^a	0.14 ± 0.09	-0.47 ± 0.08	0.00 ± 0.13	0.08 ± 0.03	-0.20 ± 0.02	-0.04 ± 0.02
15.0 ^a	0.08 ± 0.10	-0.29 ± 0.08	0.00 ± 0.15	0.10 ± 0.03	-0.23 ± 0.02	-0.03 ± 0.02

^a The criterion of normalized χ^2 did not clearly indicate that a fit which included $P_3(\cos \theta)$ was statistically justified for these energies. The error given for a_1 and a_3 reflects this uncertainty.

ELEM. SYM.	A	Z
Co	55	27

METHOD	REF. NO.	
	78 We 4	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$ P,G	RLX	13-20	D	8-15	UKN-D		DST

Analysis of data in reference 3.

POLARIZED PROTONS

Measurements of cross sections and analyzing powers are examined for polarized proton capture on ^{14}C , ^{30}Si , ^{54}Fe , ^{56}Fe , ^{58}Fe , ^{59}Co , and ^{88}Sr at energies which cover the giant dipole resonance region. These data are used to extract the relative amplitudes and phases of the contributing $E1$ T -matrix elements. A typical result exhibits two solutions. Calculations using the direct (or a direct-semidirect) capture model appear to provide a means for choosing the physical solution.

NUCLEAR REACTIONS: $^{14}\text{C}(\bar{p}, \gamma_0)$, $^{30}\text{Si}(\bar{p}, \gamma_0)$, $^{54}\text{Fe}(\bar{p}, \gamma_0)$, $^{56}\text{Fe}(\bar{p}, \gamma_0)$, $^{58}\text{Fe}(\bar{p}, \gamma_0)$, $^{59}\text{Co}(\bar{p}, \gamma_0)$, $^{88}\text{Sr}(\bar{p}, \gamma_0)$; measured $\sigma(\theta)$ and $A(\theta)$ over energy region of the giant dipole resonance. Deduced T -matrix amplitudes and phases. Compare results to direct-semidirect model calculations.

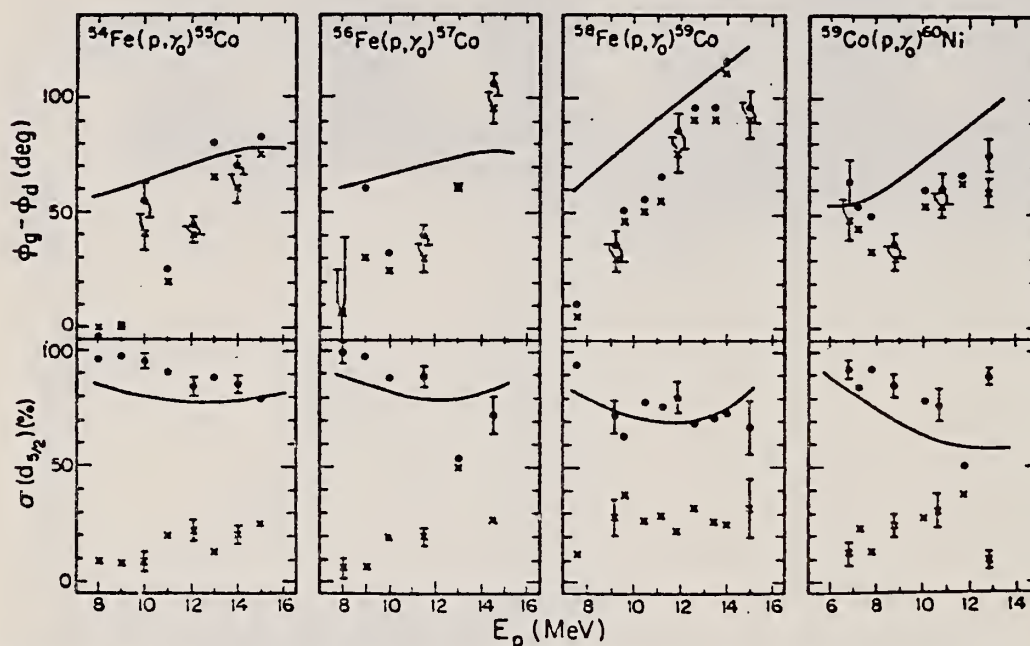


FIG. 2. Same as Fig. 1 for the target nuclei of ^{54}Fe , ^{56}Fe , ^{58}Fe , and ^{59}Co . The remaining cross section is due to the $g_{3/2}$ matrix element.

FIG. 1. The two solutions (dots and x's) resulting from a pure $E1$ analysis of the data are shown along with the results of the calculation for target nuclei of ^{14}C , ^{88}Sr , and ^{30}Si . The remaining cross section in the case of ^{14}C and ^{88}Sr is due to the $s_{1/2}$ matrix element. In the case of ^{30}Si it arises from the $p_{1/2}$ matrix element. The error bars represent typical statistical errors associated with the data points. The amplitudes are presented in terms of the percentage of the total cross section for which they are responsible. The curves represent DSD calculations as described in the text. The dashed curves in the case of ^{88}Sr were obtained using the optical model parameters of Ref. 16 while the solid lines were obtained from the parameters of Ref. 18.

(OVER)

- ²H. R. Weller, R. A. Blue, N. R. Roberson, D. G. Rickel, S. Maripuu, C. P. Cameron, R. D. Ledford, and D. R. Tilley, Phys. Rev. C 13, 922 (1976). (Note: an error exists in the sign of the phase in this paper. The quantity $\phi_3 - \phi_4$ should be $\phi_4 - \phi_3$ wherever it appears.)
- ³C. P. Cameron, N. R. Roberson, D. G. Rickel, R. D. Ledford, H. R. Weller, R. A. Blue, and D. R. Tilley, Phys. Rev. C 14, 553 (1976).
- ⁴C. P. Cameron, Ph.D. thesis, Duke University, 1976 (unpublished).
- ⁵R. D. Ledford, Ph.D. thesis, Duke University, 1976 (unpublished).
- ⁶J. D. Turner, C. P. Cameron, N. R. Roberson, H. R. Weller, and D. R. Tilley, Phys. Rev. C 17, 1853 (1978).

ELEM. SYM.	A	Z
Co	55	27
REF. NO.		
80 Ha 5		egf

METHOD					REF. NO.		
					80 Ha 5		egf
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P, G	J PI	6-7	D	1-2	SCD-D		DST

Complete angular distribution and mixing ratio data given in Table 1 10 STATES 6.2-7.3 MEV
for all states listed in Table II.

The Doppler-shift attenuation (DSA) measurements of γ -rays performed on five $^{54}\text{Fe}(p, \gamma)^{55}\text{Co}$ resonances yielded mean lifetimes of 20 levels in ^{55}Co below 5.5 MeV, seven of them for the first time. Angular distribution measurements were carried out on 17 $^{54}\text{Fe}(p, \gamma)^{55}\text{Co}$ resonances in the energy range $E_p = 1.1$ –2.3 MeV. The analysis of the angular distributions along with the present DSA and available literature data lead to the following unique spin and parity assignments for four bound states: $5/2^-$ ($E_x = 2659$ keV), $5/2^-$ (3725), $3/2^-$ (4164) and $5/2^-$ (4548). The spin of the 3563 keV state was found to be $3/2$. The unique spin values of eight resonance states were determined. The present results are compared with recent shell-model calculations.

Table II. The spin values of ^{55}Co excited states obtained in the present experiment. The energies are from [22]

Resonance states			Bound states	
E_p (keV)	E_x (keV)	J^π	E_x	J^π
→ 1162	6205	$5/2^+$	2659	$5/2^-^b$
1226	6268	$5/2^-$	2918	$7/2^-^b$
1288	6328	$3/2^-$	2939	$1/2^-(3/2)^-$
1329	6369	$5/2^+$	2976	$9/2^-(7/2)^b$
→ 1476	6513	$3/2(5/2)$	3563	$3/2$
→ 1667	6701	$5/2$	3725	$5/2^-^b$
1680	6713	$1/2^-(3/2)^-^a$	4164	$3/2^-$
→ 1722	6755	$5/2$	4177	$5/2^-$
→ 1747	6780	$3/2^-^b$	4548	$5/2^-$
1803	6834	$3/2, 5/2^c$	4748	$3/2^-^f$
→ 1846	6876	$7/2^-, 9/2^b$		
→ 1887	6917	$5/2^-^d$		
→ 2075	7101	$5/2$		
→ 2168	7193	$5/2$		
2245	7269	$3/2^-^e$		
2270	7293	$5/2^-^b$		
→ 2297	7319	$5/2$		

^a Possible analogue of the 1919($1/2^-$) keV state in ^{55}Fe [15, 17].

^b For the parity assignment see Section 4.1.

^c This resonance has been suggested to be a doublet [7], the lower member of which is the analogue of the 2051($3/2^-$) keV state in ^{55}Fe .

^d Analogue of the 2144($5/2^-$) keV state in ^{55}Fe [7, 25].

^e Possible analogue of the 2471($3/2^-$) keV state in ^{55}Fe [6].

^f Analogue of the ground state ($J^\pi = 2/2^-$) of ^{55}Fe [11, 15, 17].

ground state gamma transitions observed for states
marked with arrows

ELEM. SYM.	A	Z
Co	55	27
REF. NO.		hg
80 U1 2		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	RLY	6	D	1	SCD-D		DST
		(6.754)		(1.721)			

Abstract: Excitation functions for the $^{54}\text{Fe}(p, \gamma)^{55}\text{Co}$ reaction have been recorded in the energy region $E_p = 1100\text{--}1760$ keV. The decay schemes and branching ratios of ten resonances have been investigated. Angular distributions of primary γ -rays have been measured for three resonances to establish resonance spins. Resonance strengths for six resonances and gamma widths for three resonances have been determined. The isobaric analogues of the ground ($J^\pi = \frac{7}{2}^-$) and 1919 keV ($J^\pi = \frac{3}{2}^-$) states of the parent nucleus ^{55}Fe have been identified at 4722 and 6712 keV respectively in ^{55}Co . The Coulomb displacement energies of the observed analogue pairs (0–4722 keV) and (1919–6712 keV) have been obtained. The strengths of the possible analogue-antianalogue transitions for the proton capture state at $E_p = 1679$ keV have also been determined.

J-PI, 6754 KEV

E

NUCLEAR REACTIONS $^{54}\text{Fe}(p, \gamma)$, $E = 1.100\text{--}1.760$ MeV; measured $\sigma(E; E_p, \theta)$. ^{55}Co deduced levels, analogue resonances, J, δ , resonance strengths, gamma widths. Enriched target.

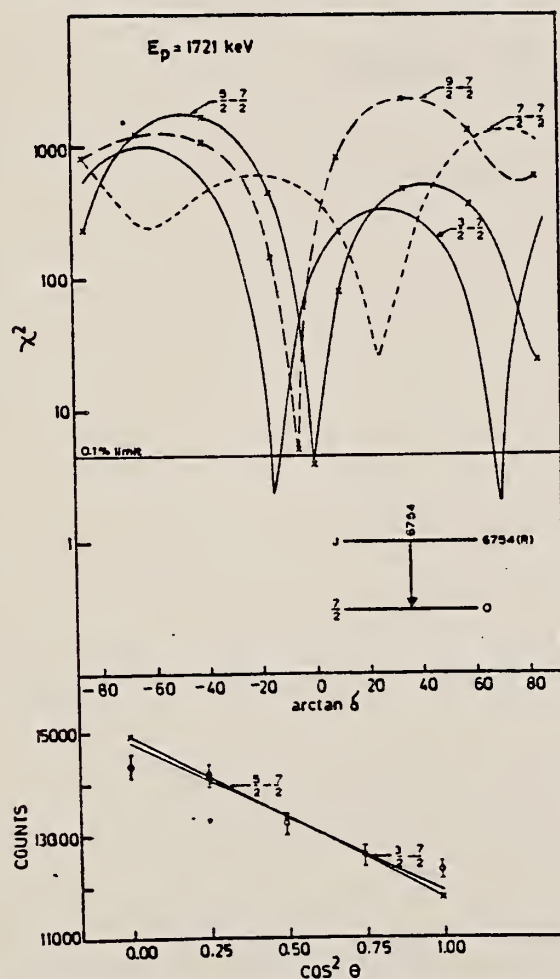


Fig. 5. Angular distribution for the transition from the proton capture state at $E_p = 1721$ keV to ground state and the corresponding χ^2 plots.

(OVER)

TABLE 3
Results of the angular distributions for the dominant primary transitions

Res- onance E_p (keV)	Transition E_i-E_f (keV)	Spin sequence J_i-J_f	χ^2 min	Mixing ratio δ	Legendre polynomial coefficients		
					A_0	a_2	a_4
1747	6780-2167	$\frac{1}{2}-\frac{1}{2}$	2.01	$-3.72^{+0.35}_{-1.04}$	1044 ± 21	0.38 ± 0.04	0.006 ± 0.04
		$\frac{1}{2}-\frac{1}{2}$	1.82	$0.00^{+0.03}_{-0.02}$			
		$\frac{1}{2}-\frac{1}{2}$	2.71	$-0.36^{+0.02}_{-0.02}$			
	6780-2566	$\frac{1}{2}-\frac{1}{2}$	1.41	$-1.43^{+0.18}_{-0.08}$	1334 ± 23	0.93 ± 0.04	0.06 ± 0.04
		$\frac{1}{2}-\frac{1}{2}$	1.48	$-0.36^{+0.04}_{-0.09}$			
		$\frac{1}{2}-\frac{1}{2}$	1.14	$-0.08^{+0.03}_{-0.02}$			
	6780-3324	$\frac{1}{2}-\frac{1}{2}$	1.14	$2.14^{+0.12}_{-0.14}$	788 ± 24	-0.39 ± 0.06	0.02 ± 0.06
		$\frac{1}{2}-\frac{1}{2}$	0.96	$0.57^{+0.06}_{-0.03}$			
		$\frac{1}{2}-\frac{1}{2}$	1.00	$3.73^{+0.35}_{-0.70}$			
		$\frac{1}{2}-\frac{1}{2}$	0.99	$0.00^{+0.01}_{-0.02}$			
		$\frac{1}{2}-\frac{1}{2}$	2.60	$1.73^{+1.21}_{-0.45}$			
		$\frac{1}{2}-\frac{1}{2}$	2.32	$-0.27^{+0.02}_{-0.005}$			
1721	6754-0	$\frac{1}{2}-\frac{1}{2}$	1.89	$2.74^{+0.07}_{-0.14}$	13691 ± 107	-0.11 ± 0.01	0.003 ± 0.01
		$\frac{1}{2}-\frac{1}{2}$	3.76	$0.00^{+0.02}_{-0.005}$			
		$\frac{1}{2}-\frac{1}{2}$	0.56	$0.46^{+0.03}_{-0.03}$			
	6754-2167	$\frac{1}{2}-\frac{1}{2}$	0.52	$5.67^{+1.44}_{-0.65}$	543 ± 5	0.21 ± 0.33	-0.57 ± 1.24
		$\frac{1}{2}-\frac{1}{2}$	0.53	$-0.08^{+0.02}_{-0.02}$			
		$\frac{1}{2}-\frac{1}{2}$	14.40	$2.75^{+1.96}_{-1.15}$			
		$\frac{1}{2}-\frac{1}{2}$	1.23	$0.27^{+0.01}_{-0.04}$			
		$\frac{1}{2}-\frac{1}{2}$	1.38	$-0.17^{+0.01}_{-0.04}$			
1679	6712-2167	$\frac{1}{2}-\frac{1}{2}$	0.17	$0.08^{+0.02}_{-0.01}$	1732 ± 37	0.02 ± 0.04	0.04 ± 0.04
		$\frac{1}{2}-\frac{1}{2}$	0.28	$2.74^{+0.15}_{-0.14}$			
		$\frac{1}{2}-\frac{1}{2}$	12.57	$-2.74^{+1.10}_{-1.96}$			
	6712-2918	$\frac{1}{2}-\frac{1}{2}$	0.63	$0.36^{+0.02}_{-0.02}$	1321 ± 41	0.001 ± 0.05	0.04 ± 0.05
		$\frac{1}{2}-\frac{1}{2}$	0.68	$-0.36^{+0.02}_{-0.02}$			
		$\frac{1}{2}-\frac{1}{2}$	0.68	$5.67^{+0.69}_{-0.64}$			
	6712-3324	$\frac{1}{2}-\frac{1}{2}$	0.78	$0.17^{+0.02}_{-0.07}$	700 ± 29	0.17 ± 0.23	0.51 ± 0.69
		$\frac{1}{2}-\frac{1}{2}$	0.61	$-0.27^{+0.12}_{-0.01}$			
		$\frac{1}{2}-\frac{1}{2}$					
		$\frac{1}{2}-\frac{1}{2}$					

Co
A=57

Co
A=57

Co
A=57

ELEM. SYM.	A	Z
Co	57	27
REF. NO.		
74 Es 3		egf

METHOD					REF. NO.	
					74 Es 3	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR	
			TYPE	RANGE	TYPE	RANGE
P, G	LFT	7- 8	D	1- 2	SCD-D	
				(1.2-1.5)		

TABLE 1
Branching ratios in percent determined in the present work

E_x (keV)	J^π	Resonance proton energy (keV)															
		1223	1275	1280	1301	1311	1328	1345	1351	1372	1403	1408	1416	1420	1452	1458	1465
4685	$\frac{1}{2}^+$															29	11
4251	$\frac{1}{2}^+$																
4197	$\frac{1}{2}^+$																
4064	$\frac{1}{2}^+$										11		3				
3993	$\frac{1}{2}^+$	4										35					
3856	$\frac{1}{2}^+$							12									
3723	$\frac{1}{2}^+$	7										5			12		
3701	$\frac{1}{2}^+$																7
3467	$\frac{1}{2}^+$												9				13
3357	$\frac{1}{2}^+$			3									7	3			
3262	$\frac{1}{2}^+$		19														
3176	$\frac{1}{2}^+$	11		16								13	5	6		9	
3109	$\frac{1}{2}^+$																8
2981	$\frac{1}{2}^+$		2														
2879	$\frac{1}{2}^+$							16				4	8	6			
2803	$\frac{1}{2}^+$										12	8			5		20
2743	$\frac{1}{2}^+$																
2730	$\frac{1}{2}^+$	4		18							8			9			6
2723	$\frac{1}{2}^+$																
2611	$\frac{1}{2}^+$				13							10				6	
2560	$\frac{1}{2}^+$																
2524	$\frac{1}{2}^+$																
2485	$\frac{1}{2}^+$																
2311	$\frac{1}{2}^+$				9								20	16		6	
2133	$\frac{1}{2}^+$			5								8	30	26			
1920	$\frac{1}{2}^+$	7				38	13			38	39	4		5	21		
1897	$\frac{1}{2}^+$											4	4			12	
1757	$\frac{1}{2}^+$	19	24			62	87		10			4	5	18	20	14	11
1689	$\frac{1}{2}^+$																
1505	$\frac{1}{2}^+$	35	20	36					13		27		2		42		9
1378	$\frac{1}{2}^+$	12	35	22	20			67	49	62		2	2			5	15
1223	$\frac{1}{2}^+$																
0	$\frac{1}{2}^+$	1			58			33			3	3	5	3		19	

The level energies, spins and parities, are those of ref. 7). Exceptions are discussed in the text. The resonance at $E_p = 1351$ keV is an unresolved doublet ⁶).

TABLE 3
Results of absolute yield measurements for four of the resonances studied

Resonance proton energy (keV)	$(2J+1)I_p\Gamma_\gamma/(I_p+\Gamma_\gamma)$ (eV)
1223	0.30
1403	0.20
1408	0.45
1416	0.34

Taking into account uncertainties in the target composition we view these results as uncertain to $\pm 30\%$ in absolute value. Other sources of uncertainty contribute less than 5%.

(over)

TABLE 2
Angular distribution results for the dominant primary transitions

Decay	Spin sequence	χ^2	Mixing ratio	Legendre polynomial coefficients	
				A_2	A_4
$E_p = 1223 \text{ keV}$					
$R \rightarrow 1505$	$\frac{3}{2} \rightarrow \frac{1}{2}$	0.6	0.09 ± 0.05	-0.63 ± 0.04	-0.01 ± 0.03
		0.6	1.43 ± 0.05		
$E_p = 1301 \text{ keV}$					
$R \rightarrow 1377$	$\frac{3}{2} \rightarrow \frac{3}{2}$	0.2	-0.05 ± 0.03	-0.27 ± 0.05	-0.04 ± 0.05
		21	0.38 ± 0.4		
	$\frac{3}{2} \rightarrow \frac{1}{2}$	0.2	0.51 ± 0.15		
		0.2	4.71 ± 0.3		
$E_p = 1403 \text{ keV}$					
$R \rightarrow 1505$	$\frac{3}{2} \rightarrow \frac{1}{2}$	0.3	-0.02 ± 0.09	-0.46 ± 0.09	0.02 ± 0.1
		0.3	1.80 ± 0.1		
$R \rightarrow 1920$	$\frac{3}{2} \rightarrow \frac{1}{2}$	0.3	-19.1 ± 0.05	-0.41 ± 0.03	0.01 ± 0.03
		0.3	-0.29 ± 0.05		
$R \rightarrow \text{g.s.}$	$\frac{3}{2} \rightarrow \frac{7}{2}$	1.3	0.12 ± 0.3	0.45 ± 0.1	-0.50 ± 0.1
		1.3	1.10 ± 0.3		
$R \rightarrow 4064$	$\frac{3}{2} \rightarrow \frac{1}{2}$	0.1	0.02 ± 0.06	-0.50 ± 0.1	-0.00 ± 0.1
		0.1	1.70 ± 0.1		
	$\frac{3}{2} \rightarrow \frac{3}{2}$	0.1	0.84 ± 0.2		
		0.1	2.15 ± 0.2		
$E_p = 1408 \text{ keV}$					
$R \rightarrow 1757$	$\frac{3}{2} \rightarrow \frac{3}{2}$	0.1	-0.02 ± 0.04	-0.35 ± 0.1	0.02 ± 0.05
		18	2.25 ± 0.4		
$R \rightarrow 1920$	$\frac{3}{2} \rightarrow \frac{3}{2}$	0.5	-0.75 ± 0.3	0.64 ± 0.06	-0.06 ± 0.07
		0.3	-0.27 ± 0.4		
$R \rightarrow 3993$	$\frac{1}{2} \rightarrow \frac{5}{2}$	8.9	-1.28 ± 0.2	0.48 ± 0.03	0.03 ± 0.03
		0.3	-0.04 ± 0.03		
$R \rightarrow \text{g.s.}$	$\frac{1}{2} \rightarrow \frac{7}{2}$	0.1	-0.05 ± 0.03	-0.18 ± 0.07	-0.03 ± 0.07
		0.8	19.1 ± 0.14		
$R \rightarrow 1896$	$\frac{1}{2} \rightarrow \frac{1}{2}$	1.4	19.1 ± 0.09	-0.30 ± 0.07	-0.04 ± 0.06
		0.4	0.14 ± 0.02		
$R \rightarrow 2131$	$\frac{1}{2} \rightarrow \frac{1}{2}$	1.2	0.14 ± 0.4	0.55 ± 0.05	0.10 ± 0.06
$E_p = 1416 \text{ keV}$					
$R \rightarrow 2879$	$\frac{1}{2} \rightarrow \frac{1}{2}$	0.2	0.07 ± 0.04	-0.52 ± 0.09	0.01 ± 0.08
		6.7	1.60 ± 0.2		
$R \rightarrow 1757$	$\frac{1}{2} \rightarrow \frac{3}{2}$	0.9	-0.05 ± 0.1	-0.35 ± 0.09	0.13 ± 0.09
		4.3	2.48 ± 0.4		
$R \rightarrow 2131$	$\frac{1}{2} \rightarrow \frac{3}{2}$	7.6	-0.1 ± 0.6	0.05 ± 0.03	0.01 ± 0.03
		0.1	0.07 ± 0.03		
$R \rightarrow 4064$	$\frac{1}{2} \rightarrow \frac{3}{2}$	1.1	0.04 ± 0.15	-0.45 ± 0.2	-0.00 ± 0.2
		4.3	1.80 ± 0.7		
$R \rightarrow 3357$	$\frac{1}{2} \rightarrow \frac{3}{2}$	0.1	0.14 ± 0.04	-0.11 ± 0.04	-0.00 ± 0.04
		56	3.5 ± 0.4		
$R \rightarrow 3467$	$\frac{1}{2} \rightarrow \frac{1}{2}$	0.4	$0. \pm 0.02$	-0.41 ± 0.08	0.01 ± 0.1
		54	2.14 ± 0.2		
$R \rightarrow \text{g.s.}$	$\frac{1}{2} \rightarrow \frac{5}{2}$	0.0	-0.07 ± 0.05	-0.24 ± 0.06	0.00 ± 0.05
		0.9	29.0 ± 0.1		
$R \rightarrow 2311$	$\frac{1}{2} \rightarrow \frac{3}{2}$	0.1	-0.02 ± 0.03	-0.14 ± 0.04	-0.01 ± 0.04
		2.0	11.4 ± 0.14		
$E_p = 1420 \text{ keV}$					
$R \rightarrow 1757$	$\frac{1}{2} \rightarrow \frac{3}{2}$	0.2	0.02 ± 0.02	-0.40 ± 0.06	0.01 ± 0.05
		17	1.90 ± 0.3		
$R \rightarrow 2133$	$\frac{1}{2} \rightarrow \frac{5}{2}$	0.6	0.23 ± 0.6	0.63 ± 0.06	0.01 ± 0.07

⁶L.S. August, G.R. Gossett and P.A. Treado, Phys. Rev. 142 (1966) 664

⁷G. Hardie, T.H. Braid, L. Meyer-Schutzmeister and J.W. Smith, Phys. Rev. C5 (1972) 1600

J.V. Maher, L. Meyer-Schutzmeister, E.L. Sprenkel-Segel,
D. von Ehrenstein, R.J. Nemanich, G.C. Kiáng, J.F. Tonn, R.E. Segel
Phys. Rev. C9, 1440 (1974)

ELEM. SYM.	A	Z
Co	57	27
REF. NO.		
74 Ma 1		hmg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	ABX	10- 24	D	4- 18	NAI-D		DST

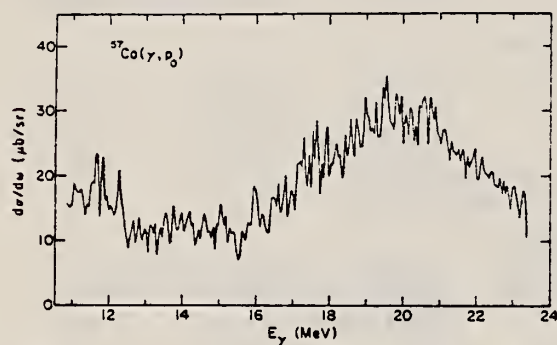


FIG. 4. Yield curve at 90° for the $^{57}\text{Co}(\gamma, p_0)$ reaction.

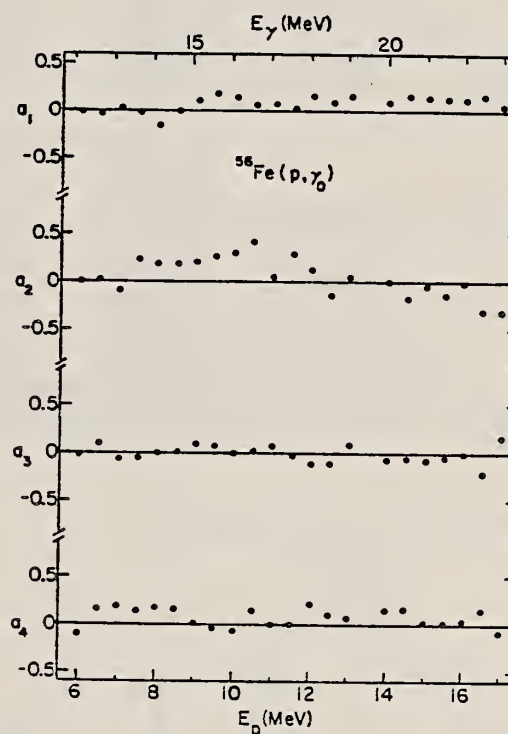


FIG. 8. Angular-distribution coefficients for the $^{56}\text{Fe}(p, \gamma_0)$ reaction.

REF.

C.P. Cameron, N.R. Roberson, D.G. Rickel, R.D. Ledford,
H.R. Weller, R.A. Blue, D.R. Tilley
phys. Rev. C14, 553 (1976)

ELEM. SYM.

A

Z

Co

57

27

METHOD

REF. NO.

76 Ca 4

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$P, G	ABX	14- 24	D	8- 15	NAI-D		DST

POLARIZED PROTONS

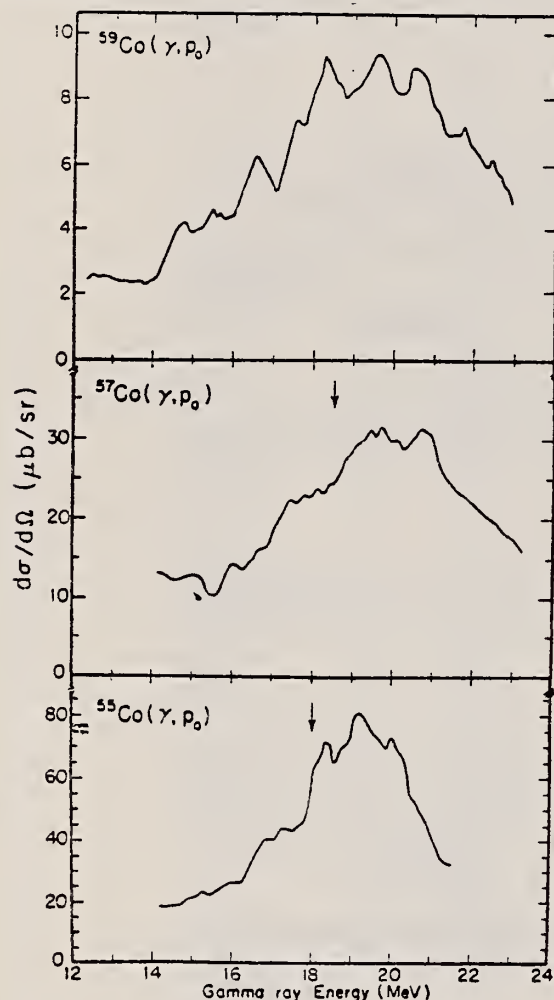


FIG. 3. The 90° yield curves for the $^{54,56,58}\text{Fe}(p, \gamma)$ reactions after averaging over a 500 keV interval. The arrows indicate the energy of the splitting between the $T_{\frac{1}{2}}$ and $T_{\frac{3}{2}}$ components of the GDR as suggested in Ref. 1.

$$\sigma(\theta) = a_0 \left[1 + \sum_i \frac{a_i}{a_0} Q_i P_i(\cos\theta) \right],$$

$$A(\theta) = \left(\frac{N_+ - N_-}{N_+ + N_-} \right) \frac{1}{P} \quad \text{(Where } N_+ \text{ and } N_- \text{ are counts spin up and counts spin down.)}$$

$$A(\theta)\sigma(\theta)/a_0 = \sum_i b_i Q_i P_i^2(\cos\theta).$$

- ¹J.V. Maher, L. Meyer-Schutzmeister, E.L. Sprenkel-Segel, D. von Ehrenstein, R.J. Nemanich, G.C. Kiang, J.F. Tonn, and R.E. Segel, Phys. C9, 1440 (1974).

(over)

TABLE III. The a and b coefficients obtained from least square fits to the data as described in the text. Higher order coefficients are given only when the criterion of normalized χ^2 justified the use of higher order terms.

E_p (MeV)	a_1/a_0	a_2/a_0	a_3/a_0	b_1	b_2	b_3
$^{54}\text{Fe}(\bar{p}, \gamma)^{55}\text{Co}$						
8.0	0.26 ± 0.06	0.11 ± 0.11		-0.03 ± 0.05	0.00 ± 0.04	-0.02 ± 0.04
9.0	0.20 ± 0.05	0.09 ± 0.10		-0.07 ± 0.04		
10.0	0.25 ± 0.04	0.03 ± 0.07		0.02 ± 0.03	-0.09 ± 0.02	
11.0	0.10 ± 0.03	0.24 ± 0.05		0.03 ± 0.02	-0.07 ± 0.02	
12.1	0.27 ± 0.05	0.18 ± 0.04	0.18 ± 0.07	0.01 ± 0.01	-0.12 ± 0.01	
13.0	0.01 ± 0.03	-0.09 ± 0.05		0.03 ± 0.02	-0.15 ± 0.01	
14.0	0.07 ± 0.03	0.0 ± 0.05		-0.02 ± 0.02	-0.16 ± 0.02	-0.02 ± 0.02
15.0	0.18 ± 0.03	-0.12 ± 0.06		0.01 ± 0.02	-0.20 ± 0.02	-0.03 ± 0.02
$^{56}\text{Fe}(\bar{p}, \gamma)^{57}\text{Co}$						
8.0	0.27 ± 0.06	0.03 ± 0.12		0.08 ± 0.05	-0.01 ± 0.04	
9.0	0.07 ± 0.04	-0.04 ± 0.08		-0.05 ± 0.03	-0.06 ± 0.02	-0.03 ± 0.02
10.0	0.08 ± 0.03	0.24 ± 0.06		0.05 ± 0.02	-0.08 ± 0.02	-0.02 ± 0.02
11.5	0.03 ± 0.03	0.20 ± 0.05		-0.08 ± 0.03	-0.09 ± 0.02	
13.0	0.14 ± 0.03	0.15 ± 0.05		0.02 ± 0.02	-0.22 ± 0.02	-0.03 ± 0.02
14.5	0.14 ± 0.04	-0.34 ± 0.08		0.10 ± 0.03	-0.21 ± 0.02	-0.04 ± 0.02
$^{58}\text{Fe}(\bar{p}, \gamma)^{57}\text{Co}$						
7.6	0.19 ± 0.05	0.19 ± 0.09		0.04 ± 0.03	-0.02 ± 0.03	
9.2	0.12 ± 0.04	0.28 ± 0.07		0.01 ± 0.03	-0.11 ± 0.02	
9.6	0.04 ± 0.04	0.26 ± 0.07		0.06 ± 0.02	-0.17 ± 0.02	
10.5	0.12 ± 0.04	0.15 ± 0.06		0.04 ± 0.02	-0.17 ± 0.02	0.04 ± 0.02
11.2	0.16 ± 0.04	0.09 ± 0.06		0.08 ± 0.02	-0.18 ± 0.02	
11.9	0.18 ± 0.05	-0.14 ± 0.09		0.03 ± 0.03	-0.20 ± 0.03	-0.04 ± 0.03
12.7	0.13 ± 0.05	-0.25 ± 0.09		0.07 ± 0.03	-0.23 ± 0.02	
13.5 ^a	0.08 ± 0.09	-0.28 ± 0.09	0.00 ± 0.14	0.06 ± 0.03	-0.22 ± 0.02	
14.0 ^a	0.14 ± 0.09	-0.47 ± 0.08	0.00 ± 0.13	0.08 ± 0.03	-0.20 ± 0.02	-0.04 ± 0.02
15.0 ^a	0.08 ± 0.10	-0.29 ± 0.08	0.00 ± 0.15	0.10 ± 0.03	-0.23 ± 0.02	-0.03 ± 0.02

^a The criterion of normalized χ^2 did not clearly indicate that a fit which included $P_3(\cos \theta)$ was statistically justified for these energies. The error given for a_1 and a_3 reflects this uncertainty.

ELEM. SYM.	A	Z
Co	57	27
REF. NO.		
78 Fo 3		rs

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P, G	LFT	9	D	4	SCD-D		DST

9=9.689, 9.696

Abstract. Resonances consistent with fragmented $g_{9/2}$ analogue resonance have been found in ^{57}Co corresponding to the $E_x = 2.454$ MeV level in the ^{57}Fe parent nucleus. The resonance was located through the $^{56}\text{Fe}(p, \gamma)^{57}\text{Co}$ reaction. Total γ -ray spectra were measured with a Ge(Li) detector in 2 keV steps in the expected proton energy range. Excitation functions for the different primary γ transitions were constructed. The $g_{9/2}$ IAR were found in two components at $E_p = 3728$ and 3735 keV. The angular distributions of γ rays were measured at these two bombarding proton energies. The two resonances were suggested to have spin and parity $J^\pi = \frac{3}{2}^+$ based on the γ -ray excitation functions and angular distribution measurements. The γ -ray branchings and absolute transition probabilities were also determined. The M1 γ transitions from the $g_{9/2}$ IAR components going to the possible anti-analogue level at $E_x = 4.585$ MeV excitation energy have absolute transition strengths of 1.8×10^{-2} Wu and 1.2×10^{-2} Wu.

Table 1. Summary of the Legendre polynomial coefficients and comparison of the mixing ratio δ with the Weisskopf estimate for the transitions studied.

Proton energy (keV)	Excitation energy (MeV)	Transition $E_i \rightarrow E_f$ (MeV)	Legendre polynomial		Transition Character $J_i^\pi \rightarrow J_f^\pi$	Weisskopf estimate for $|\delta|$	Mixing ratio experiment	Assigned spin and parity
			A_2/A_0	A_4/A_0				
3728	9-689	9-689 \rightarrow 0-000	-0.26 ± 0.09	0.002 ± 0.06	$\frac{3}{2}^+ \rightarrow \frac{7}{2}^-$	0.003	0.04 ± 0.04	$J_\pi^\pi = \frac{3}{2}^+$
					$\frac{3}{2}^+ \rightarrow \frac{5}{2}^-$	0.22	0.04 ± 0.04	
					$\frac{7}{2}^- \rightarrow \frac{7}{2}^-$	0.22	0.90 ± 0.08	
3735	9-696	9-696 \rightarrow 0-000	-0.39 ± 0.04	0.02 ± 0.06	$\frac{3}{2}^+ \rightarrow \frac{7}{2}^-$	0.003	-0.04 ± 0.04	$J_\pi^\pi = \frac{3}{2}^+$
					$\frac{3}{2}^+ \rightarrow \frac{5}{2}^-$	0.22	-0.04 ± 0.04	
					$\frac{7}{2}^- \rightarrow \frac{7}{2}^-$	0.22	-1.27 ± 0.09	
3728	9-689	9-689 \rightarrow 4-585	0.46 ± 0.08	-0.02 ± 0.05	$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	0.11	-0.04 ± 0.08	$J_i^\pi = \frac{3}{2}^+$
					$\frac{3}{2}^+ \rightarrow \frac{7}{2}^-$	0.002	0.40 ± 0.08	
3735	9-696	9-696 \rightarrow 4-585	0.43 ± 0.08	-0.03 ± 0.10	$\frac{3}{2}^+ \rightarrow \frac{3}{2}^+$	0.11	-0.07 ± 0.08	$J_i^\pi = \frac{3}{2}^+$
					$\frac{3}{2}^+ \rightarrow \frac{7}{2}^-$	0.002	-0.40 ± 0.09	

Table 2. γ -ray transition strength leading to different excited states measured on top of the resonances at $E_p = 3728$ and 3735 keV (calculated by thick-target estimate). The Γ_γ values were deduced supposing $\Gamma_i \approx \Gamma_p$.

E_i^{final} (MeV)	J^π	$E_p = 3728$ keV			$E_p = 3735$ keV		
		$\omega(\Gamma_p \Gamma_\gamma / \Gamma_i)$ (keV)	Γ_γ (eV)	$\Gamma_\gamma / \Gamma_{Wu}$	$\omega(\Gamma_p \Gamma_\gamma / \Gamma_i)$ (keV)	Γ_γ (eV)	$\Gamma_\gamma / \Gamma_{Wu}$
0-000	$\frac{7}{2}^-$ $\frac{5}{2}^-$ $\frac{3}{2}^-$ $\frac{1}{2}^-$ $\frac{3}{2}^+$	1.0×10^{-4}	0.24	3.0×10^{-4}	1.0×10^{-4}	0.23	3.0×10^{-4}
2-611		1.0×10^{-4}	0.02		0.8×10^{-4}	0.02	
2-723		0.7×10^{-4}	0.01		0.8×10^{-4}	0.02	
2-743		0.7×10^{-4}	0.01		0.7×10^{-4}	0.01	
4-585		3.0×10^{-4}	0.05	1.8×10^{-2}	2.0×10^{-4}	0.03	1.2×10^{-2}

ELEM. SYM.	A	Z
Co	57	27
METHOD		
REF. NO.		
78 We 4		hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$ P,G	RLX	14-31	D	8-15	UKN-D		DST

Analysis of data in reference 3.

POLARIZED PROTONS

Measurements of cross sections and analyzing powers are examined for polarized proton capture on ^{14}C , ^{30}Si , ^{54}Fe , ^{56}Fe , ^{58}Fe , ^{59}Co , and ^{88}Sr at energies which cover the giant dipole resonance region. These data are used to extract the relative amplitudes and phases of the contributing $E1$ T -matrix elements. A typical result exhibits two solutions. Calculations using the direct (or a direct-semidirect) capture model appear to provide a means for choosing the physical solution.

NUCLEAR REACTIONS: $^{14}\text{C}(\bar{p}, \gamma_0)$, $^{30}\text{Si}(\bar{p}, \gamma_0)$, $^{54}\text{Fe}(\bar{p}, \gamma_0)$, $^{56}\text{Fe}(\bar{p}, \gamma_0)$, $^{58}\text{Fe}(\bar{p}, \gamma_0)$, $^{59}\text{Co}(\bar{p}, \gamma_0)$, $^{88}\text{Sr}(\bar{p}, \gamma_0)$; measured $\sigma(\theta)$ and $A(\theta)$ over energy region of the giant dipole resonance. Deduced T -matrix amplitudes and phases. Compare results to direct-semidirect model calculations.

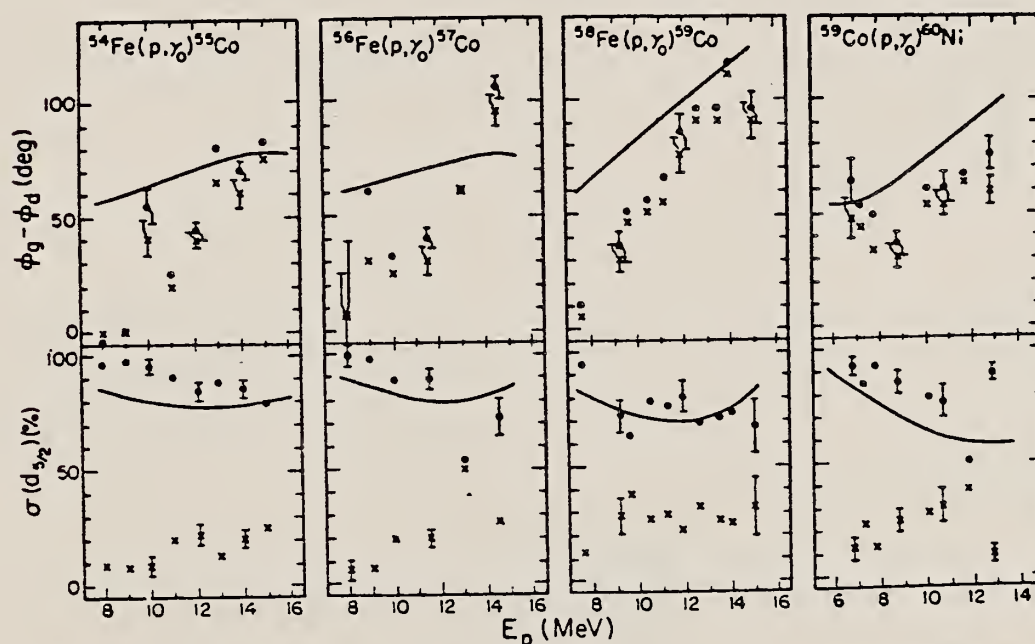


FIG. 2. Same as Fig. 1 for the target nuclei of ^{54}Fe , ^{56}Fe , ^{58}Fe , and ^{59}Co . The remaining cross section is due to the $g_{3/2}$ matrix element.

FIG. 1. The two solutions (dots and \times 's) resulting from a pure $E1$ analysis of the data are shown along with the results of the calculation for target nuclei of ^{14}C , ^{88}Sr , and ^{30}Si . The remaining cross section in the case of ^{14}C and ^{88}Sr is due to the $s_{1/2}$ matrix element. In the case of ^{30}Si it arises from the $p_{1/2}$ matrix element. The error bars represent typical statistical errors associated with the data points. The amplitudes are presented in terms of the percentage of the total cross section for which they are responsible. The curves represent DSD calculations as described in the text. The dashed curves in the case of ^{88}Sr were obtained using the optical model parameters of Ref. 16 while the solid lines were obtained from the parameters of Ref. 18.

- ²H. R. Weller, R. A. Blue, N. R. Roberson, D. G. Rickel, S. Maripuu, C. P. Cameron, R. D. Ledford, and D. R. Tilley, Phys. Rev. C 13, 922 (1976). (Note: an error exists in the sign of the phase in this paper. The quantity $\phi_4 - \phi_3$ should be $\phi_4 - \phi_2$ wherever it appears.)
- ³C. P. Cameron, N. R. Roberson, D. G. Rickel, R. D. Ledford, H. R. Weller, R. A. Blue, and D. R. Tilley, Phys. Rev. C 14, 553 (1976).
- ⁴C. P. Cameron, Ph.D. thesis, Duke University, 1976 (unpublished).
- ⁵R. D. Ledford, Ph.D. thesis, Duke University, 1976 (unpublished).
- ⁶J. D. Turner, C. P. Cameron, N. R. Roberson, H. R. Weller, and D. R. Tilley, Phys. Rev. C 17, 1853 (1978).

ELEM. SYM.	A	Z
Co	57	27
REF. NO.		
81 E1 1		hg

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
P,G	LFT	7	D	1	SCD-D		DST
		(7.598)		(1.599)			

The yield curve of the reaction $^{56}\text{Fe}(p,\gamma)^{57}\text{Co}$ has been measured over the energy range $E_p=1,300\text{--}1,900\text{ keV}$ and the decay of nine resonances has been investigated. For twelve of the resonances the strengths have been determined. The angular distributions of the gamma rays have been recorded for resonances at $E_p=1,599, 1,623, 1,643$ and $1,649\text{ keV}$, giving spin-parity assignments $J^\pi=3/2^-$ for all four resonances. The resonances at $E_p=1,623, 1,643$ and $1,649\text{ keV}$ have been identified as the split analogue resonances of the 367 ($J^\pi=3/2^-$) states in ^{57}Fe . The M1 transition strengths to the corresponding antianalogue states have been measured and compared with theoretical predictions.

Table 3. Resonance strengths for the resonances in the $^{56}\text{Fe}(p,\gamma)^{57}\text{Co}$

(a) $E_p \pm 2$ (keV)	(a) ω_γ ($\pm 35\%$)	(a) J^π	(a) Γ_γ (eV)	(b) E_p (keV)	(b) ω_γ ($\pm 30\%$)	(b) J^π	(b) Γ_γ (eV)
1,403	0.30			1,403	0.20	3/2	
1,408	0.42			1,408	0.45	5/2	
1,416	0.39			1,416	0.34	5/2	
1,453	0.43			1,452		(1/2, 3/2)	
1,460	0.38			1,458		(5/2)	
1,466	0.40			1,465		(1/2, 3/2)	
1,525	0.60						
1,557	0.42						
1,599	0.88	3/2-	0.22				
1,623	1.33	3/2-	0.33	1,622.7		3/2, 5/2	
1,643	1.12	3/2-	0.28	1,645.8	0.90	3/2	0.20
1,649	2.30	3/2-	0.58	1,651.9	2.0	3/2	0.50

(a) Present Work (b) Ref. 5, 10

Table 4. Partial radiative widths for transitions in ^{57}Co

Transition resonance to	$E_p=1,599$ keV Γ_γ (meV)	$E_p=1,623$ keV Γ_γ (meV)	$E_p=1,643$ keV Γ_γ (meV)	$E_p=1,649$ keV Γ_γ (meV)
G.S.	122			
1,378	9	176	24.4	279
1,505			150	97
1,758	39		8	
1,920		17	57	29
2,133	9			29
2,731	17	27		
2,803		27		
2,879			11	
2,981		31		
3,108			11	40
3,177	22	31	5	
3,268				40
3,357		31	5	17
3,993				40

Table 1. Summary of the Legendre polynomial coefficients for the studied transitions

Proton energy (keV)	Excitation energy (keV)	Transition $E_i \rightarrow E_f$ (keV)	Legendre Polynomial	
			$A_1 A_0$	$A_2 A_0$
1,599	7,598	7,598 \rightarrow g.s.	-0.197 ± 0.015	0.026 ± 0.018
		7,598 \rightarrow 1,758	-0.223 ± 0.012	-0.017 ± 0.014
1,623	7,622	7,622 \rightarrow 1,378	0.337 ± 0.022	-0.041 ± 0.025
1,643	7,641	7,641 \rightarrow 1,378	0.042 ± 0.019	-0.006 ± 0.02
		7,641 \rightarrow 1,505	-0.201 ± 0.016	-0.004 ± 0.02
		7,641 \rightarrow 1,920	-0.227 ± 0.015	0.002 ± 0.02
1,649	7,647	7,647 \rightarrow 1,378	0.285 ± 0.019	-0.039 ± 0.02
		7,647 \rightarrow 1,505	-0.299 ± 0.054	-0.057 ± 0.064

(over)

LEVEL 7.598, JPI

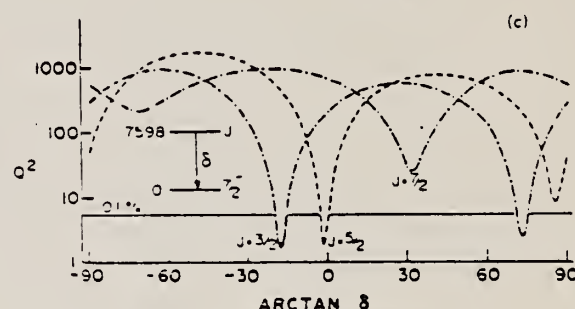
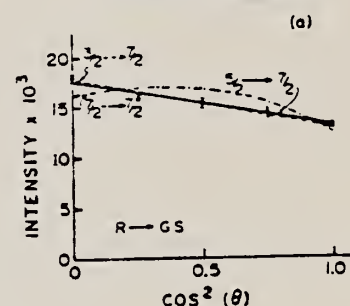


Fig. 3a-d. (a) and (b) Experimental angular distribution data and theoretical fits to transitions from the resonant state to ground state and 1758 respectively. (c) and (d) show Q^2 versus $\arctan \delta$ from fitting experimental angular distribution to theory for different spin values for γ -rays from the resonant state at 7,598 keV to the ground state and to the 1,758 keV state in ^{57}Co , respectively

Table 2. Experimental mixing ratios δ compared with Weisskopf values for states of ^{57}Co studied here

Resonance $E_r \pm 2$ (keV)	Transition $E_i \rightarrow E_f$ (keV)	Transition $J_i^{\pi} \rightarrow J_f^{\pi}$	Character	Weisskopf estimate for $|\delta|$	Experimental mixing ratio δ	Assigned J_i^{π}
1.599	7.598 \rightarrow 0	$3/2^{+} \rightarrow 7/2^{-}$	$M2(E3)$	0.04	-0.325 ± 0.018	$3/2^{-}$
		$3/2^{-} \rightarrow 7/2^{-}$	$E2(M3)$	0.003		
		$5/2^{+} \rightarrow 7/2^{-}$	$E1(M2)$	0.004	-0.035 ± 0.018	
		$5/2^{-} \rightarrow 7/2^{-}$	$M1(E2)$	0.249		
	7.598 \rightarrow 0	$3/2^{-} \rightarrow 3/2^{-}$	$M1(E2)$	0.20	0.445 ± 0.014	
		$3/2^{+} \rightarrow 3/2^{-}$	$E1(M2)$	0.003		
		$5/2^{+} \rightarrow 3/2^{-}$	$E1(M2)$	0.002	-0.07 ± 0.011	
		$5/2^{-} \rightarrow 3/2^{-}$	$M1(E2)$	0.20		
1.623	7.622 \rightarrow 1.378	$3/2^{-} \rightarrow 3/2^{-}$	$M1(E2)$	0.20	0.07 ± 0.018	$3/2^{-}$
		$3/2^{+} \rightarrow 3/2^{-}$	$E1(M2)$	0.003		
1.643	7.641 \rightarrow 1.505	$3/2^{-} \rightarrow 1/2^{-}$	$M1(E2)$	0.20	-0.176 ± 0.018	$3/2^{-}$
		$3/2^{+} \rightarrow 1/2^{-}$	$E1(M2)$	0.003		
	7.641 \rightarrow 1.920	$3/2^{-} \rightarrow 5/2^{-}$	$M1(E2)$	0.20	-0.105 ± 0.018	
		$3/2^{+} \rightarrow 5/2^{-}$	$E1(M2)$	0.003		
1.649	7.647 \rightarrow 1.378	$3/2^{-} \rightarrow 3/2^{-}$	$M1(E2)$	0.20	0.07 ± 0.018	$3/2^{-}$
		$3/2^{+} \rightarrow 3/2^{-}$	$E1(M2)$	0.003		
	7.647 \rightarrow 1.505	$3/2^{-} \rightarrow 1/2^{-}$	$M1(E2)$	0.20	-0.105 ± 0.012	
		$3/2^{+} \rightarrow 1/2^{-}$	$E1(M2)$	0.003		

Co
A=58

Co
A=58

Co
A=53

METHOD

REF. NO.

70 Er 1

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
P,G	SPC	8-9	D	1-2	SCD-D	1-9	45

DETAILS 4 LEVELS

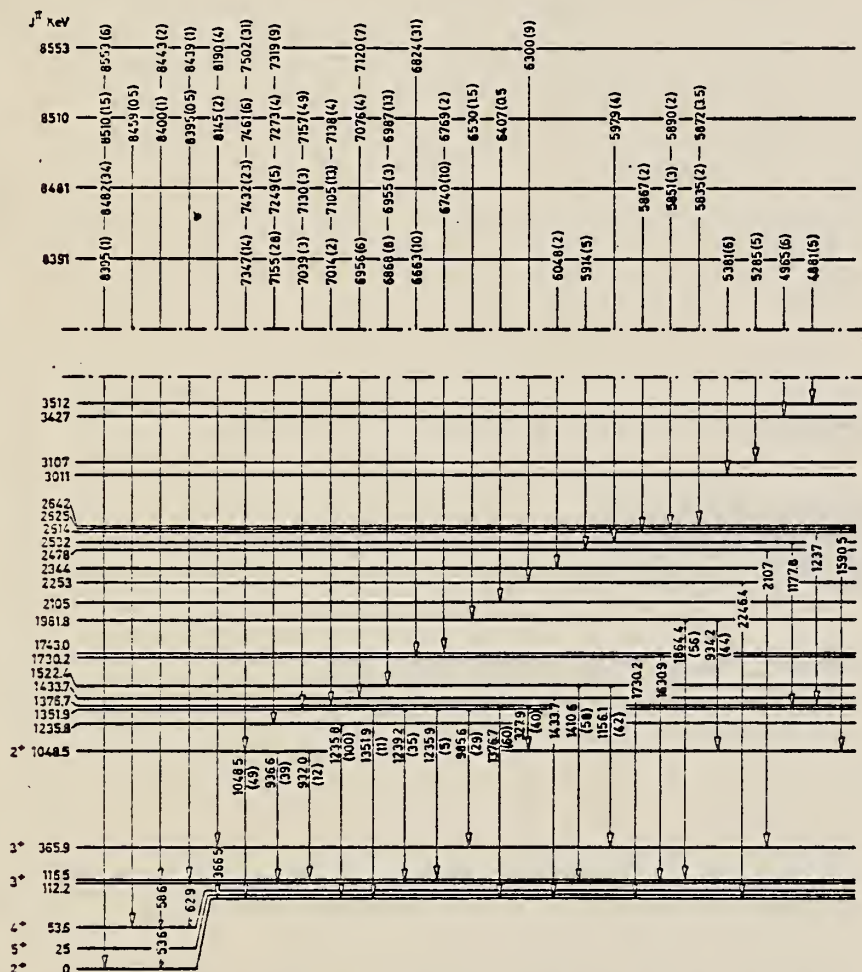


Fig. 5. The proposed decay scheme. Spin and parity values are taken from Trier *et al.* ⁸).

⁸A. Trier, J. Rapaport, T. A. Belote and W. E. Dorenbusch,
Nucl. Phys. A134 (1969) 396.

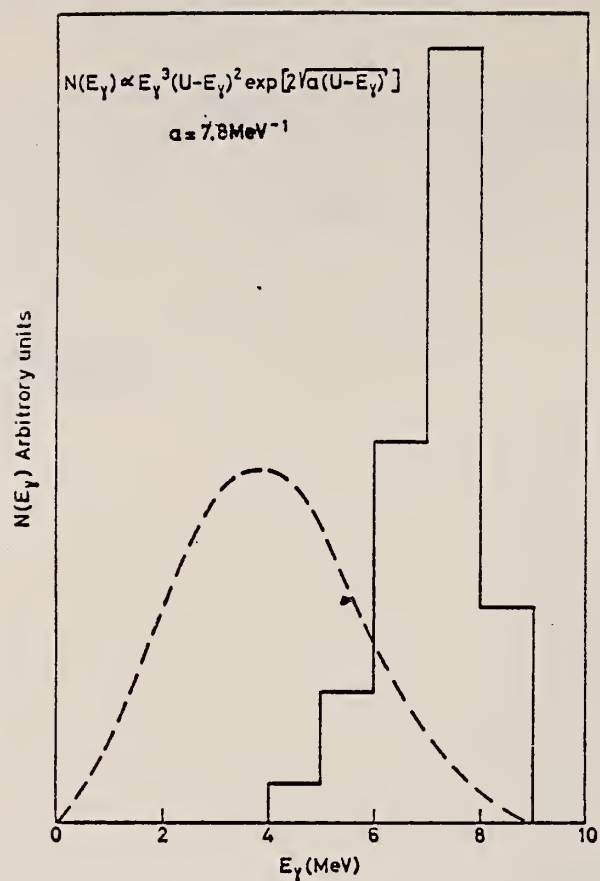


Fig. 7. Integrated spectrum of the primary γ -rays from the proton capture states at the four resonances investigated. The dashed line shows the spectrum according to the formula given in the figure. The constant a is taken from Glower and Purser ²⁸). The area under the theoretical curve is normalized to the numbers of γ -rays in the experimental curve.

²⁸U. Fanger, W. Michaelis, H. Schmidt and H. Ottmar, Nucl. Phys. A123 (1969) 641.

Co
A=59

Co
A=59

Co
A=59

REF.

B. Forkman
Arkiv Fysik 11, 265-75 (1956)

ELEM. SYM.

A

Z

Co

59

27

METHOD

Synchrotron; ion chamber

REF. NO.

56 Fo 1

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
1) G,D	RLY	15-30	C	30	EMU-D		90
2) G,P	RLY	7-30	C	30	EMU-D		90

$$\frac{Y(\gamma, d)}{Y(\gamma, p)} = 0.22$$

1) YLD REL TO G,P2) YLD REL TO G,D

Method Li(p, γ) source; 480 keV protons; BF₃ counter

Ref. No.	EGF
56 Ha 1	

Reaction	E or ΔE	E _o	Γ	$\int \sigma dE$	J π	Notes
Co ⁵⁹ (γ ,xn)						Average Li cross section is 49 mb; cross section with detector response weighted for low energy neutrons, 49 mb. Assumed ratio 17.6/14.8 = 1.7. Calculated cross section at 14.8 and 17.6 MeV assuming cross section curves measured at Pennsylvania and Saskatchewan (refer Table I).

TABLE I. Cross sections for photoneutron emission induced by the lithium gamma rays. The results are compared with previous data.

Element	Present cross-section data		Data of McDaniel <i>et al.</i> ^a	Betatron data					
	Counter Group A	Counter Group B		Pennsylvania		Saskatchewan		$\sigma_{14.8}^b$	$\sigma_{17.6}^b$
				$\sigma_{14.8}^b$	$\sigma_{17.6}^b$	$\sigma_{14.8}^b$	$\sigma_{17.6}^b$		
⁵⁴ Fe	38 mb	33 mb	37 mb			60 ^c mb	0.5	23 mb	47 mb
⁵⁷ Co	49	49	47	60 ^a mb	0.5	95 ^c	0.5	30	60
⁵⁸ Ni	28	25	23			40 ^c	0.7	22	32
⁶³ Cu	64	61	55±12			95 ^c	0.6	45	75
⁶⁶ Zn	48	45	48			90 ^c	0.7	38	54
⁶⁷ Ag	175	170	135			240 ^c	1.0	175	175
¹⁰⁰ Sn	200	190	180						
⁷¹ Ta	355	360	260	350 ^d	1.3	420 ^c	2.3	420 ^d	320 ^d
						550 ^d		550 ^d	240 ^d
⁷⁴ W	365	355	325						
⁷⁹ Au	330	295		315 ^e	1.7	480 ^f	1.9	460	255
⁸⁰ Hg	365	340	290						
⁸² Pb	310	295	250	320 ^e	1.6	440 ^f	2.5	400 ^d	250 ^d
						500 ^d		500 ^d	200 ^d
⁸³ Bi	305	280	250	270 ^d	2.6	550 ^f	2.4	490	195

^a McDaniel, Walker, and Stearns, Phys. Rev. 80, 807 (1950).
^b Montalbetti, Katz, and Goldemberg, Phys. Rev. 91, 659 (1953).
^c R. Nathans and J. Halpern, Phys. Rev. 93, 437 (1954).
^d J. Goldemberg and L. Katz, Can. J. Phys. 32, 49 (1954).
^e Burkhardt, Winhold, and Dupree, Phys. Rev. 100, 199 (1955), and references therein.

REF.

F. Heinrich and H. Waffler
 Helv. Phys. Acta 29, 232 (1956)

ELEM. SYM.

A

Z

Co

59

27

METHOD

REF. NO.

56 He 1

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,T	RLY	THR-31	C	31	ACT-I		4PI

Yields relative to (G,N) yields.

Tabelle 1.
 Experimentelle und theoretische nukleare Ausbeute der (γ , T)-Prozesse.

Element	$\eta_{\text{exp}} \times 10^4$	$\eta_{\text{theor}} \times 10^4$
Al	240 ± 14	200
Co	$6 \pm 1,7$	4
Cu	$4,5 \pm 1,5$	3

METHOD

REF. NO.

56 Wa 1

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,T	RLY	THR - 31	C	31	ACT-I		4PI

Detected activity of tritium. Yields are relative to $^{63}\text{Cu}(\gamma, n)$.

Reaction	Threshold energy MeV	$\eta_{\text{exp}} \times 10^5$	$\eta_{\text{theor}} \times 10^5$
Al	18.2 ± 0.2	34 ± 2	31
Co	16.5 ± 0.3	7 ± 2	5
^{63}Cu	16.2 ± 0.3	6 ± 2	4
^{65}Cu	15.1 ± 0.3		
^{107}Ag	13.9 ± 0.6	6.5 ± 1	0.4
^{109}Ag	13.1 ± 0.6		

The table shows the calculated yield ratios (according to statistical theory) as well as the measured relative yield

$$\eta = \int_0^{31 \text{ MeV}} N(E_\gamma) \sigma^{(z)}(\gamma, t) E_\gamma dE_\gamma / \int_0^{31 \text{ MeV}} N(E_\gamma) \sigma^{(63\text{Cu})}(\gamma, t) E_\gamma dE_\gamma$$

taking the (γ, n) yield on ^{63}Cu as unity. The good agreement between the experimental

REF.

Miroslav Rozkoš
Czech. J. Phys. 7, 592 (1957)

ELEM. SYM.

A

Z

Co

59

7

METHOD

REF. NO.

57 Ro 1

EGF

[Page 1 of 2]

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	SPC	15,18	D	15,18	EMU-D	3-7	DST

14.8 and 17.6 MeV photons.

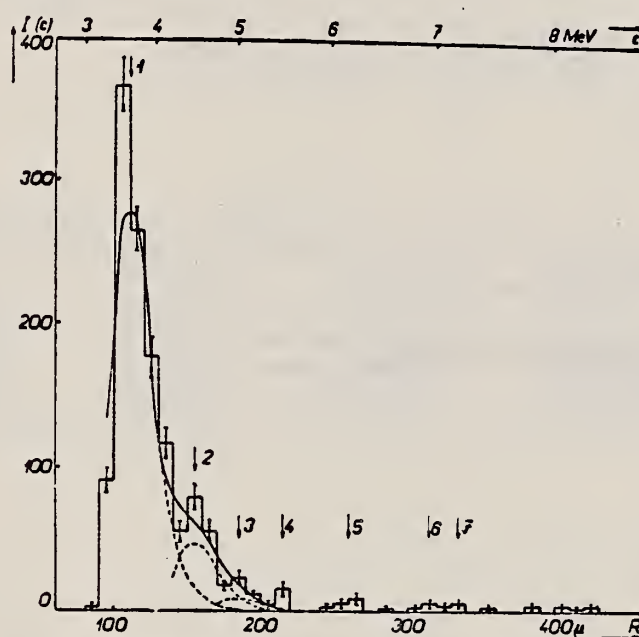


Рис. 1. Энергетическое распределение фотопротонов в интервале $\theta \sim 30^\circ - 70^\circ$ (пластинка III). Ось абсцисс нижняя: пролет R протонов в микронах, верхняя: соответствующая энергия ϵ протонов в MeV. Ось ординат: число протонов $I(\epsilon)$. Полная линия означает измеренные значения, вертикальные отрезки — экспериментальные ошибки; прерывистая линия удовлетворяет распределению Пуассона, сплошная кривая — сумма отдельных распределений. В целом использовано 1323 следа.

METHOD

REF. NO.

[Page 2 of 2]

57 Ro 1

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	

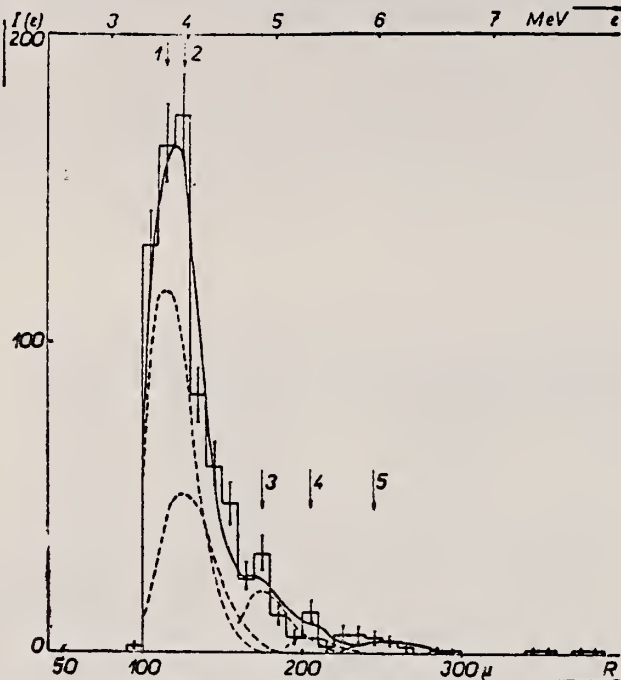


Рис. 2. Энергетическое распределение фотопротонов в интервале углов $\theta \sim 60^\circ - 90^\circ$ (пластинка II). На оси вынесены те же величины, что и на рис. 1. В целом использовано 779 следов.

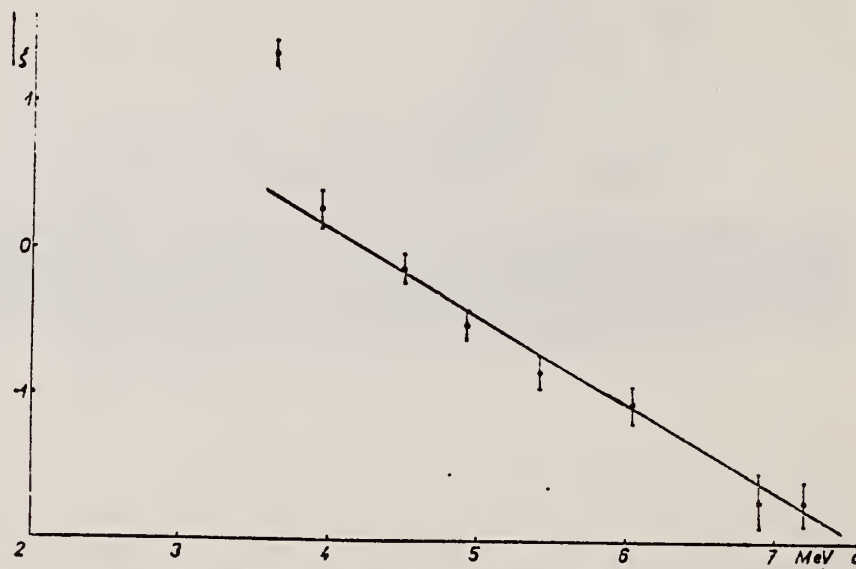


Рис. 3. Энергетическое распределение фотопротонов, обработанное по уравнению (1). Ось абсцисс: ϵ — энергия протонов в MeV. Ось ординат: $\zeta = \log \frac{I(\epsilon)}{\epsilon \cdot \sigma(\epsilon)}$. Из направляющей прямой определена температура $\Theta = 0,74 \pm 0,16$ MeV. В целом использовано 2102 следа.

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		NVB
58 Ch 2		

Betatron

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, N	RLY	THR	C	THR	BF ₃ -I		4PI

See 58 Ka 1 for cross sections

TABLE I

THRESHOLD

MEASURED PHOTONEUTRON THRESHOLDS

Reaction	Measured Q value, Mev.	Other Q values, Mev.	Method	Reference
Co ⁵⁸ (γ , n)Co ⁵⁷	10.44 \pm 0.05	10.25 \pm 0.20 10.491 \pm 0.012 10.490 \pm 0.012	Threshold { Mass data Q ⁺ value Mass data	Sher <i>et al.</i> (1951) Duckworth (unpublished) Way <i>et al.</i> (1955) Quisenberry <i>et al.</i> (1956)

TABLE II

COMPARISON OF THRESHOLDS FROM MASS DATA AND FROM PHOTONEUTRON REACTIONS

Reaction	Photoneutron threshold, Mev.	Mass data threshold, Mev.	Difference, Mev.
Na ²³ (γ , n)Na ²²	12.47 \pm 0.05	12.417 \pm 0.014	-0.05 \pm 0.05
Al ²⁷ (γ , n)Al ²⁶	12.96 \pm 0.06	13.03 \pm 0.06	+0.07 \pm 0.08
P ³¹ (γ , n)P ³⁰	12.48 \pm 0.05	12.39 \pm 0.03	-0.09 \pm 0.06
Co ⁵⁹ (γ , n)Co ⁵⁸	10.44 \pm 0.05	10.49 \pm 0.01	+0.05 \pm 0.05
Pr ¹⁴¹ (γ , n)Pr ¹⁴⁰	9.46 \pm 0.05	9.30 \pm 0.06	-0.16 \pm 0.08

METHOD Betatron; neutron cross section; BF_3 counters; ion chamber monitor

REF. NO.

58 Ka 1

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XN	ABX	10-22	C	10-22	$\text{BF}_3\text{-I}$		4PI

Таблица 2

Пороги испускания фотонейтронов

Изотоп	$B_n, \text{Мэв}$	$B_{\gamma n}, \text{Мэв}$	Изотоп	$B_n, \text{Мэв}$	$B_{\gamma n}, \text{Мэв}$
V ⁵¹	11,16	20,5	L ¹³⁹	8,81	16,1
Mn ⁵⁵	10,14	19,2	Pr ¹⁴¹	9,46	17,6
Co ⁵⁹	10,44	18,6	Tb ¹⁵⁹	8,16	14,8
As ⁷⁵	10,24	18,1	Ho ¹⁶⁵	8,10	14,6
Y ⁸⁹	11,82	20,7	Tm ¹⁶⁹	8,00	14,7
Nb ⁹³	8,86	17,1	Lu ¹⁷⁵	7,77	14,2
Rh ¹⁰³	9,46	16,8	Ta ¹⁸¹	7,66	13,8
J ¹²⁷	9,14	16,2	Au ¹⁹⁷	7,96	13,3
Cs ¹³³	9,11	16,5	Bi ²⁰⁹	7,43	14,5

THRESHOLDS

не приведены, поскольку они превышают 22 Мэв во всех случаях, кроме золота, для которого $B_{\gamma n} = 21 \text{ Мэв}$. Свойства сечений $\sigma_0(\gamma)$ сведены в табл. 3.

Таблица 1

Изотоп	$E_{\text{манс}}, \text{Мэв}$	$\sigma_n(E_\gamma), \text{барн}$	$\Gamma, \text{Мэв}$	$\Gamma_{\gamma n}, \text{Мэв-барн}$	$\Gamma(22), 10^3 \text{ нейтрон/100 р-моль}$
V ⁵¹	18,4	0,062	5,2	0,33	1,62
Mn ⁵⁵	20,2	0,060	7,0	0,39	2,01
Co ⁵⁹	18,3	0,068	6,3	0,44	2,30
As ⁷⁵	16,4	0,090	9,5	0,74	4,25
Y ⁸⁹	17,1	0,172	5,2	0,93	5,33
Nb ⁹³	18,0	0,156	7,5	1,17	6,80
Rh ¹⁰³	17,5	0,160	9,4	1,40	8,28
J ¹²⁷	15,2	0,273	6,8	1,76	11,9
Cs ¹³³	16,5	0,238	7,7	1,59	10,7
La ¹³⁹	15,5	0,325	3,8	1,55	11,2
Pr ¹⁴¹	15,0	0,320	4,9	1,93	13,1
Tb ¹⁵⁹	15,6	0,274	9,8	2,49	18,1
Ho ¹⁶⁵	13,5	0,305	8,9	2,52	18,7
Tm ¹⁶⁹	16,4	0,250	8,4	1,91	14,9
Lu ¹⁷⁵	16,0	0,225	8,4	1,90	23,0
Ta ¹⁸¹	14,5	0,380	8,5	3,15	22,0
Au ¹⁹⁷	13,8	0,475	4,7	3,04	22,6
Bi ²⁰⁹	13,2	0,455	5,9	2,89	23,2

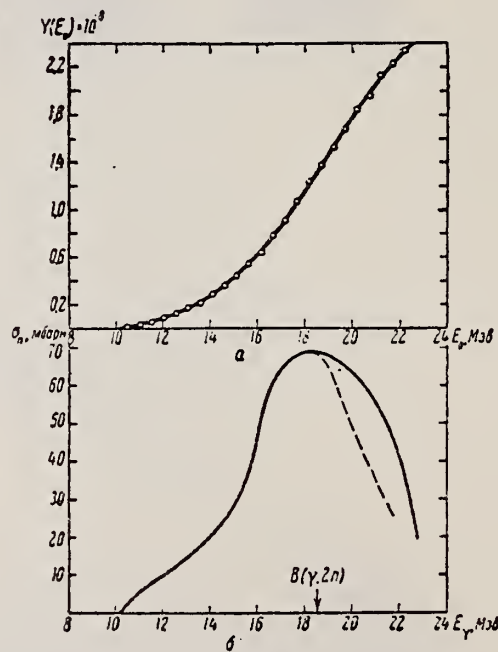


Рис. 3.

a — Выход фотонейтронов для Co; б — $\sigma_n(E_\gamma)$ и $\sigma_0(\gamma)$ для Co

Ref. M.E. Toms, J. McElhinney
Phys. Rev. 111, 561 (1958)

Elem. Sym.	A	Z
Co	59	27

Method Betatron; alpha yield; nuclear emulsion

Ref. No.	
58 To 2	NVB

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Co}^{59}(\gamma, \alpha)$	Bremss. 22					Yield = 2.3×10^4 alpha/mole/roentgen

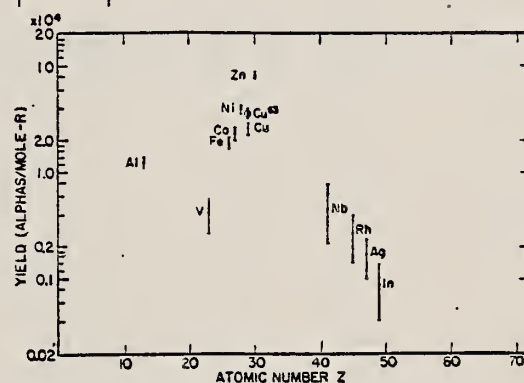


Fig. 8. Photo-alpha yields plotted against atomic numbers for the exposures of the survey.

Elem. Sym.	A	Z
Co	59	27
Ref. No.		
60 Ch 1		JHH

Method 90 MeV Bremsstrahlung; scintillator counter telescope

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Co}^{59}(\gamma, p)$						Energy Range of particles detected: $E_d - 15.5-30 \text{ MeV}$ $E_p - 15.5-30 \text{ MeV}$ $E_t - 17-30 \text{ MeV}$ Ratios: $\sigma(\gamma, d)/\sigma(\gamma, p) \}$ at $\theta = 90^\circ$ $\sigma(\gamma, t)/\sigma(\gamma, d)$
$\text{Co}^{59}(\gamma, d)$						
$\text{Co}^{59}(\gamma, t)$						

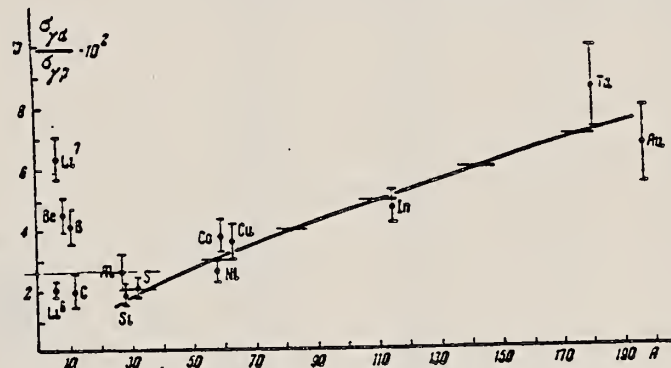
TABLE I

Element	$100N_t/N_d$	Element	$100N_t/N_d$	Element	$100N_t/N_d$	Element	$100N_t/N_d$
Li^6	30 ± 3	B	39 ± 8	Ni	10 ± 4	In	5 ± 2.5
Li^7	22.5 ± 2.5	Si	10 ± 4	Co	2.5 ± 2	Ta	10 ± 4
Be	13 ± 4.5	S	8 ± 4	Cu	2.2 ± 2	Au	3 ± 3

(over)

METHOD						REF. NO.		
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE	
			TYPE	RANGE	TYPE	RANGE		

FIG. 3. Ratio of (γ, d) to (γ, p) cross sections for protons and deuterons of energies 15.5–30 Mev as function of atomic weight A . The solid curve shows the dependence given by Eq. (2), arbitrarily normalized.



Method Synchrotron; BF_3 counters in 4π geom.

Ref. No. 60 F1 1
JHH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(γ, xn)	12-30	$16.75 \pm .25$	2.0	25MeV $709 \frac{1}{12} \text{ MeV-mb}$		$\sigma_{\text{max}}(16.75 \text{ MeV}) = 109 \text{ mb}$
		$18.75 \pm .25$	4.0			$\sigma_{\text{max}}(18.75 \text{ MeV}) = 92 \text{ mb}$
			(From Breit-Wigner Fit; see Table I)			<p>Intrinsic quadrupole moment $Q_0 = +0.76 \pm 0.11 \text{ barn}$ if</p> <p>$\sigma_{\text{total}} \approx \sigma(\gamma, n) + \sigma(\gamma, 2n)$ in this region, using $R_0 = 1.2 \times 10^{-13} \text{ cm}$.</p> <p>In Figure 5, open circles are uncorrected data; closed circles are corrected for neutron multiplicity.</p> <p>Integrated cross section is $\sigma(\gamma, n) + \sigma(\gamma, pn) + \sigma(\gamma, 2n) + \dots$</p>

TABLE I. Parameters of Breit-Wigner fit to data.

Element	E_0 (MeV)	Γ_0 (MeV)	σ_0 (mb)	E_0 (MeV)	Γ_0 (MeV)	σ_0 (mb)	$\Gamma_{\text{res}}/\Gamma_{\text{tot}}$
Manganese	16.8	2.7	70	19.75	4.0	64	1.35
Cobalt	16.5	2.0	78	19.0	4.0	78	2.00

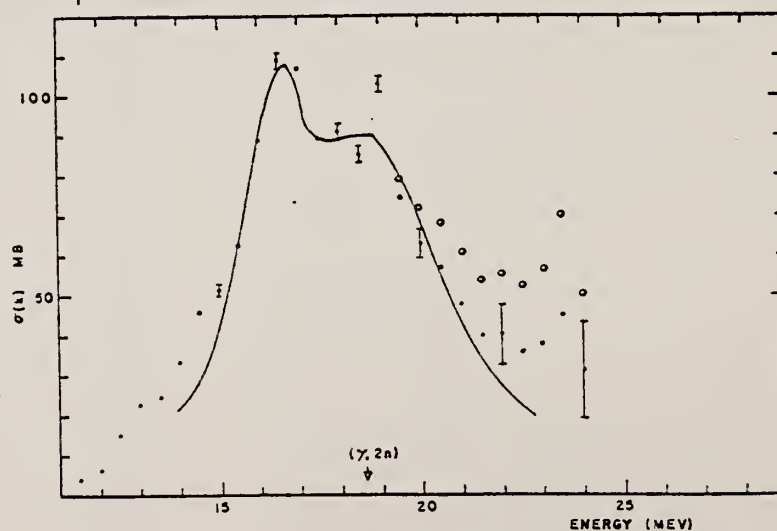


Figure 5: Neutron cross section of cobalt.

METHOD

Betatron; neutron threshold; ion chamber

REF. NO.

60 Ge 3

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NØX	THR	C	THR	BF3-I		4 PI

THRESHOLD

TABLE I. Summary and comparison of neutron separation energies inferred from present threshold measurements with values predicted from mass data and reaction energies. All energies are expressed in the center-of-mass system in Mev.

Reaction	No. runs	Present results	Other results	Method	Reference
Co ⁶⁰ (γ ,n)Co ⁶⁰	4	10.441 \pm 0.026	10.490 \pm 0.010 10.44 \pm 0.05	mass data threshold	j f

¹ See reference 4.

⁴ C. F. Giese and J. L. Benson, Phys. Rev. 110, 712 (1958).

⁵ P. M. Endt et al., Phys. Rev. 105, 1002 (1957).

¹ M. Mazari, W. W. Buechner, and A. Sperduto, Phys. Rev. 112, 1691 (1958).

¹ K. S. Quisenberry, T. T. Scolman, and A. O. Nier, Phys. Rev. 104, 461 (1956).

Ref. A.N. Gorbunov, F.P. Denisov, V.A. Kolutkhin
Zhur. Eksp. i Teoret. Fiz. 38, 1084 (1960)
Soviet Phys. JETP 11, 783 (1960)

Elem. Sym.	A	Z
Co	59	27
Ref. No.		JHH
60 Go 2		

Method 260 MeV Synchrotron; activation; B ctrs. "photon difference"

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$Co^{59}(\gamma, ?)$ Mn^{56}	30-260			$\sim 6 \text{ MeV-mb}$ (frm graph: E.H.)		Activation probably mostly due to (γ, dp) , $(\gamma, 2pn)$. (γ, He^3) also possible. Refers to "quasi-neutron mechanism."

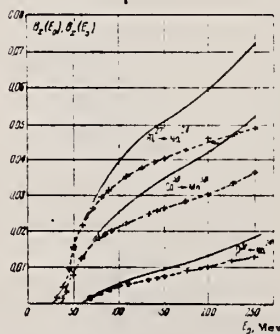


FIG. 1. Active yields of the $Al^{27} - Na^{24}$, $Co^{59} - Mn^{56}$, and $P^{31} - Na^{24}$ reactions as a function of the peak bremsstrahlung energy. The values of $B_x(E_0)$ are given by the continuous curves, of $B_x(E_a)$ - by the dashed curves (the values of $B_x(E_a)$ are given in arbitrary units).

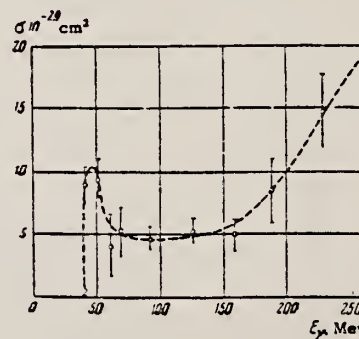


FIG. 3. Effective cross section for the $Co^{59} - Na^{24}$ reaction.

Elem. Sym.	A	Z
Co	59	

γ 's from $F^{19}(\gamma, \alpha\gamma)$ reaction; protons from Van de Graaff; NaI

60 Re 1

JHH

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$Co^{59}(\gamma, \gamma)$	~ 7					$\langle \bar{\sigma} \rangle (E_p = 2.05 \text{ MeV}) = 0.29 \pm 0.04 \text{ mb}$ Detector at 90° .

ELEM. SYM.	A	Z
Co	59	27
REF. NO. 61 Ba 2		NVB

METHOD						REF. NO.			
Betatron; fast neutron yield, angular distribution; Si threshold detector; ion chamber						61 Ba 2		NVB	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE		
			TYPE	RANGE	TYPE	RANGE			
G,XN	ABY	THR-22	C	22	THR-I	5-+	DST		

In Table 4:

$\bar{\sigma}$ = average cross section of detector
weighted with neutron spectrum

Φ = neutrons/100 roentgen/mole

$$W(\theta) = a_0 \sum_{n=1}^{\infty} [1/A_n P_n(\cos \theta)]$$

TABLE IV

I Element	II a_0	III a_1	IV a_2	V $(\bar{\sigma}\Phi) \times 10^{22}$	VI $\Phi_{total} (22 \text{ Mev}) \times 10^9$	VII Φ_{fast}/Φ_{total}
Vanadium	245 (1±0.06)	0.01±0.08	-0.00±0.10	6.05	0.21	0.12
Chromium	164 (1±0.03)	0.04±0.04	-0.05±0.05	4.05	0.17	0.10
Manganese	308 (1±0.02)	0.07±0.03	-0.09±0.04	7.61	0.25	0.12
Iron	200 (1±0.03)	0.05±0.04	-0.17±0.05	4.94	0.18	0.11
Cobalt	390 (1±0.02)	0.08±0.03	-0.22±0.04	9.63	0.26	0.15
Nickel	145 (1±0.05)	0.07±0.07	-0.23±0.09	3.58	0.12	0.12
Copper	347 (1±0.02)	0.05±0.03	-0.29±0.04	8.57	0.30	0.12
Arsenic	482 (1±0.03)	0.11±0.04	-0.24±0.05	11.91	0.33	0.15
Rubidium	638 (1±0.05)	0.13±0.06	-0.14±0.08	15.76		
Strontium	409 (1±0.05)	0.10±0.06	-0.17±0.08	10.10		
Yttrium	290 (1±0.10)	0.08±0.12	-0.12±0.15	7.16		
Silver	590 (1±0.04)	0.10±0.06	-0.22±0.08	14.57	0.87	0.07
Cadmium	905 (1±0.02)	0.02±0.02	-0.26±0.03	22.35		
Iodine	1133 (1±0.03)	0.04±0.04	-0.29±0.05	27.99	1.42	0.08
Barium	1048 (1±0.04)	0.10±0.06	-0.38±0.08	25.89		
Lanthanum	1595 (1±0.02)	0.02±0.03	-0.42±0.04	39.40	1.04	0.15
Cerium	1316 (1±0.05)	0.05±0.06	-0.39±0.08	32.50		
Dysprosium	1652 (1±0.08)	0.04±0.10	-0.34±0.13	40.80		
Tantalum	1558 (1±0.02)	0.04±0.03	-0.22±0.04	38.48	2.50	0.06
Tungsten	1365 (1±0.02)	-0.07±0.03	-0.24±0.04	33.71		
Mercury	1345 (1±0.02)	0.04±0.03	-0.31±0.04	33.22		
Lead	2274 (1±0.01)	0.02±0.02	-0.42±0.03	56.17	2.72	0.08
Bismuth	2162 (1±0.02)	0.05±0.03	-0.45±0.04	53.40	3.36	0.06
Thorium	3031 (1±0.04)	0.06±0.05	-0.32±0.07	74.87		
Uranium	4630 (1±0.02)	0.05±0.03	-0.17±0.04	114.36		

* $(\bar{\sigma}\Phi) = 2.47 \times 10^7 a_0$ millibarn-neutron. Errors are standard errors due to counting statistics only.

Method Linac; Čerenkov counter telescope; inelastic electron scattering
40°-90° in lab.

Ref. No.
61 Cr 1 JHH

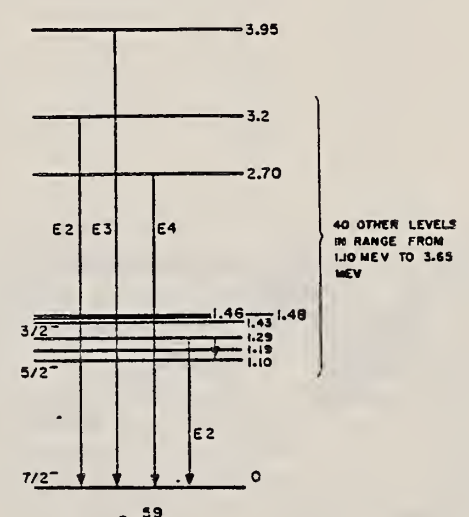
Reaction	E or ΔE	E ₀	Γ	∫σdE	Jπ	Notes
(e ⁻ , e ⁻ ')	183	1.30 2.70 3.95				<p>Measured γ transition rate, Γ_m:</p> <p>Γ_m = (7.4±0.95)10¹² sec⁻¹; (E2); G = Γ_m/Γ_{sp} = 44±5.7</p> <p>Γ_m = (1.1±0.46)10⁵ sec⁻¹; (E4); G = Γ_m/Γ_{sp} = 14.0±5.9</p> <p>Γ_m = (5.0±0.96)10¹⁰ sec⁻¹; (E3); G = Γ_m/Γ_{sp} = 16.5±3.1</p> <p>[Γ_{sp} = single-particle estimate of the γ transition rate.]</p> <p>Fits R₀ = 1.20 fermi</p> 

FIG. 13. In this and the following four figures are shown portions of the energy-level structures of the nuclei investigated in the present experiment. The information is, for the most part, taken from reference 15. The γ-ray transitions shown are those whose decay rates were determined directly in the present experiment or inferred from a knowledge of the γ-ray branching ratios in de-excitation of the nucleus. The spin and parity of each level are shown at the left, where known, and the energy of the excited states in Mev on the right. The best assignments of the transition multipolarities are indicated. This figure shows the energy-level structure of Ni⁵⁸.

FIG. 14. Energy-level diagram for Co⁵⁹. A large number of the energy levels are omitted (see reference 16). We have identified the 1.30-Mev transition induced by inelastic electron scattering with the 1.29-Mev transition known from other studies (see references 15 and 16). It is expected, from other considerations discussed in the text, that each observed electron-induced transition may excite a number of levels spaced less than about 200 kev apart. This possibility adds some uncertainty to the level scheme and to the measurements of the gamma transition rate for the 0.19-Mev ray from the 1.29-Mev level. See caption for Fig. 13.

Ref 15: Data on the decay schemes are taken principally from Nuclear Data Sheets, National Academy of Sciences - National Research Council (U.S. Government Printing Office, Washington, D.C., 1959)

Ref 16: Mazari et al - Phys. Rev. 107 365 (1957).

Elem. Sym.	A	Z
Co	59	27
Ref. No.		EGF
61 Em 1		

Method Betatron; emulsions

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
Co ⁵⁹ (γ ,xn)	Bremss. 30					90° spectra. Neutron measurement cut off at 2 MeV.

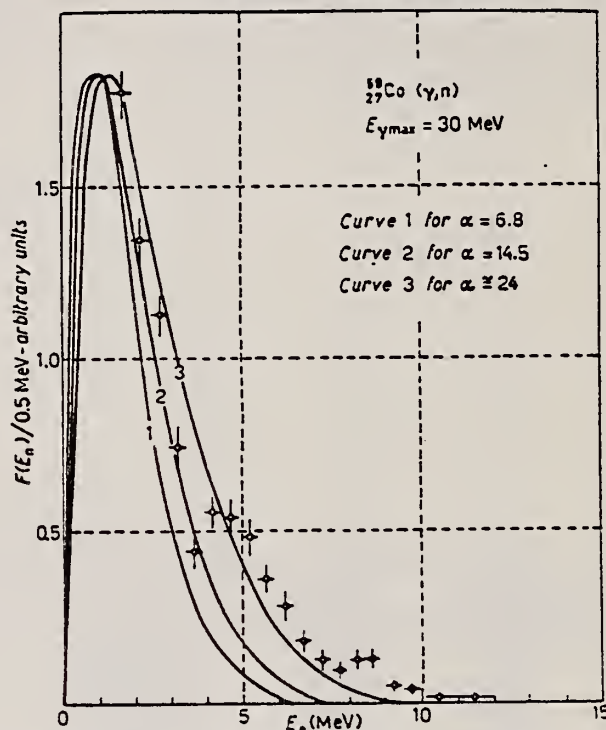


Fig. 3. - Points: experimental photoneutron spectrum from cobalt. The curves represent evaporation spectra calculated according to expression (1). For $\omega(E_n)$ given by (2): curve (1) for $\alpha=6.8$; curve (2) for $\alpha=14.5$; curve (3) for $\alpha=24$ using $\omega(E_n)$ given by (3).

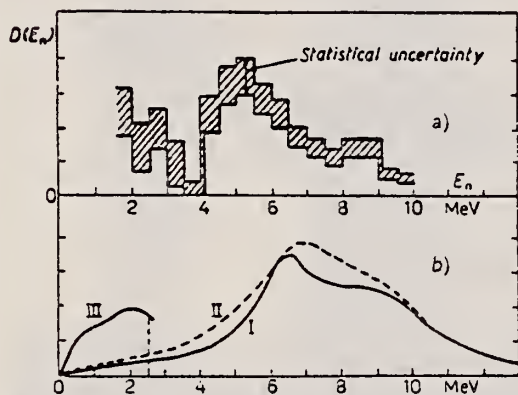


Fig. 7. - a) Expected photoneutron distribution for transition to the ground state for the (γ , n) process, curves I and II and for the (γ , 2n) process, curve III (see text). Abscissae: $E_\gamma - E_{th}(d, n)$ for curves I and II; $\frac{1}{2}[E_\gamma - E_{th}(\gamma, 2n)]$ for curve III. Ordinates: $\sigma(\gamma, n) \cdot I(E_\gamma, E_\beta)$ for curves I and II; $2\sigma(\gamma, 2n) \cdot I(E_\gamma, E_\beta)$ for curve III. b) $D(E_n)$ = difference between the experimental spectrum and the evaporation curve 2 of Fig. 3.

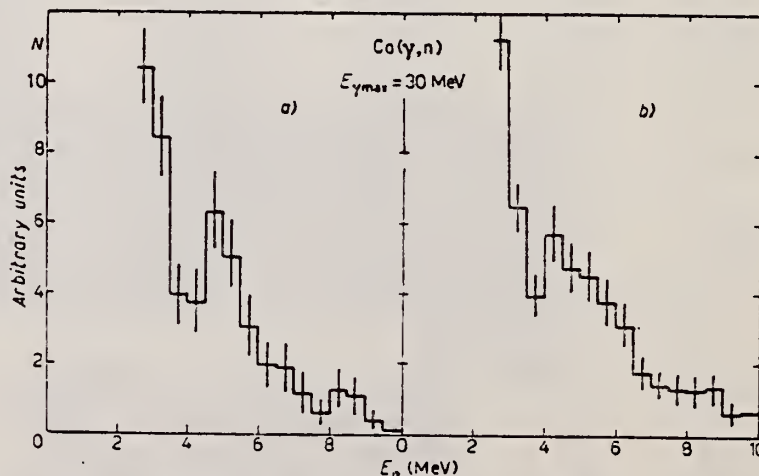


Fig. 4. - Partial photoneutron spectra from Co as measured independently at Catania (a) and Messina (b) laboratories.

Method 30 MeV electron synchrotron; emulsions; magnetic analysis

Ref. No.	JHH
61 Fo 1	

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Co}^{59}(\gamma, d)$	Bremss.			Angle Unknown		No significant (γ, d) yield detected. Ratio of yields:
$\text{Co}^{59}(\gamma, \alpha)$	30					$\frac{(\gamma, \alpha)}{(\gamma, p)} = 0.09$

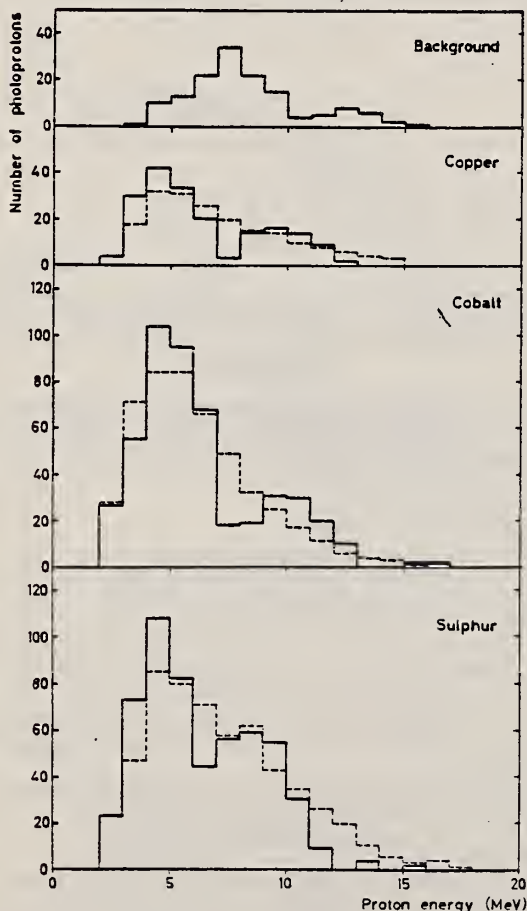


Figure 8: Energy distribution of the photoproton tracks giving intersection points in the area $-8.4 > x_t > -11.6$ and $-3.0 < x_t < 3.0$.

The lowest section shows the photoprotons from the sulphur exposure. The dashed line is the expected distribution from ref. 19 [Cujec-Dobovisek, Congr. Intern. de Physiq. Nucleaire 634, (1958)]. The second section shows the photoprotons from the cobalt exposure. The dashed line is the expected distribution from ref. 20 [Toms and Stephens, Phys. Rev. 95, 1209 (1954)]. The third section shows the photoprotons from the copper exposure. The dashed line is the expected distribution from ref. 21 [Lin'kova et al, Soviet JETP 38, 780 (1960)]. The background is subtracted in these 3 sections, but shown in the uppermost section. It originates from the entrance window.

Elem. Sym.	A	Z
Co	59	27
Ref. No.		
62 Ca 1		JHH

Method 30 MeV electron synchrotron; activation; NaI

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
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Co⁵⁹ (γ, n) Bremss.
30

TABLE I
Isomeric ratios from (γ, n) reactions

Target nucleus	J_0	Residual nucleus						Isomer ratio $Y_1/(Y_1+Y_2)$	σ
		Ground state		Metastable state		Intermediate state			
		Spin	Half-life	Spin	Half-life				
							Spin		
Co ⁵⁹	$\frac{7}{2}^-$	Co ⁵⁸	2+	71.3 d	5+	9.2 h		0.44 ± 0.02	3.2 ± 0.2
Ge ⁷⁶	0+	Ge ⁷⁵	$\frac{1}{2}^-$	82 min	$\frac{7}{2}^+$	49 s		0.48 ± 0.07	2.8 ± 0.5
Br ⁸¹	$\frac{3}{2}^-$	Br ⁸⁰	1+	18 min	5-	4.4 h	2-	0.32 ± 0.02	6.5 ± 1.0
Sr ⁸⁶	0+	Sr ⁸⁵	$\frac{3}{2}^+$	64 d	$\frac{1}{2}^-$	70 min	$\frac{7}{2}^+$	0.36 ± 0.07	2.2 ± 0.4
Zr ⁹⁰	0+	Zr ⁸⁹	$\frac{3}{2}^+$	79 h	$\frac{1}{2}^-$	4.4 min		0.33 ± 0.10	2.3 ± 0.7
Mo ⁹²	0	Mo ⁹¹	$\frac{3}{2}^+$	15.7 min	$\frac{1}{2}^-$	66 s		0.46 ± 0.04	6 ± 1
Ag ¹⁰⁷	$\frac{1}{2}^-$	Ag ¹⁰⁶	1+	24 min	6	8.3 d		0.04 ± 0.02	2.0 ± 0.3
In ¹¹³	$\frac{3}{2}^+$	In ¹¹²	1+	14.5 min	4+	20.7 min	7-	0.8 ± 0.1	3.1 ± 0.7
Cd ¹¹⁶	0+	Cd ¹¹⁵	$\frac{1}{2}^+$	53 h	$\frac{1}{2}^-$	43 d		≤ 0.2	≤ 3
Ce ¹⁴⁰	0+	Ce ¹³⁹	$\frac{3}{2}^+$	140 d	$\frac{1}{2}^-$	55 s		0.03 ± 0.01	2.5 ± 0.2
Hg ¹⁹⁸	0+	Hg ¹⁹⁷	$\frac{1}{2}^-$	65 h	$\frac{1}{2}^+$	24 h	$\frac{3}{2}^-$	0.05 ± 0.01	3.4 ± 0.5

Ref.	Previous work							
Br ⁸¹ 10)	$\frac{3}{2}^-$	Br ⁸⁰	1+	18 min	5-	4.4 h	2-	0.33 6.5
Sc ⁴² 12)	0+	Sc ⁴¹	$\frac{1}{2}^-$	18 min	$\frac{7}{2}^+$	57 min		0.5 3.0
Zr ⁹⁰ 11)	0+	Zr ⁸⁹	$\frac{3}{2}^+$	79 h	$\frac{1}{2}^-$	4.3 min		0.44 ± 0.06 4.5 ± 1
In ¹¹³ 23)	$\frac{3}{2}^+$	In ¹¹²	1+	72 s	3+	50 d	8	0.85 5.0

($T_{1/2} = 2.5$ s)

The yields Y_1 and Y_2 are for (γ, n) reactions ending in the isomeric- or ground-state. The yield Y_1 is for the higher-spin state.

References

- 1) J. R. Huizenga and R. Vandenbosch, Phys. Rev. **120** (1960) 1305
- 2) T. Ericson, Advances in Physics **9** (1960) 425
- 3) D. L. Allan, Nuclear Physics **24** (1961) 274
- 4) C. T. Hibdon, Phys. Rev. **114** (1959) 179
- 5) C. T. Hibdon, Phys. Rev. **122** (1961) 1235
- 6) T. Ericson, Nuclear Physics **11** (1959) 481
- 7) J. H. Carver, and G. A. Jones, Nuclear Physics **19** (1960) 184
- 8) A. C. Douglas and N. MacDonald, Nuclear Physics **13** (1959) 382
- 9) T. Ericson and V. M. Scrutinski, Nuclear Physics **8** (1958) 284
- 10) L. Katz, L. Pease and H. Moody, Can. J. Phys. **30** (1952) 476
- 11) L. Katz, R. G. Baker and R. Montalbetti, Can. J. Phys. **31** (1953) 250
- 12) E. Silva and J. Goldemberg, An Acad. Brasil Ciencia **28** (1956) 275
- 13) J. H. Carver and D. C. Peaslee, Phys. Rev. **120** (1960) 2155
- 14) J. M. Blatt and V. F. Weisskopf, Theoretical nuclear physics (John Wiley, New York, 1952)
- 15) S. H. Vegors, L. L. Marsden and R. L. Heath, U. S. Atomic Energy Commission Report IDO-16370 (1958)
- 16) Nuclear Data Sheets (National Research Council, Washington, 1960) sets 1-5 inclusive
- 17) R. Vandenbosch and J. R. Huizenga, Phys. Rev. **120** (1960) 1313
- 18) E. Weigold and R. N. Glover, Nuclear Physics **32** (1962) 106
- 19) K. J. Le Coutur and D. W. Lang, Nuclear Physics **13** (1959) 32
- 20) T. D. Newton, Can. J. Phys. **34** (1956) 804
- 21) D. W. Lang, Nuclear Physics **26** (1961) 434
- 22) M. E. Rose, Internal conversion coefficients (North Holland Publ. Co., Amsterdam, 1958)
- 23) J. Goldemberg and L. Katz, Phys. Rev. **90** (1953) 308

Method

 e^+ annihilation - ion chamber, BF_3

Ref. No.

62Ful

BG

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
(γ, n)	8.5-28	17.5	5.9	$.447 \pm .044$ ₀ ²⁸		It is estimated that $\sigma(\gamma, p)$ would add 20% to formation cross section, i.e.: $\int [\sigma(\gamma, n) + \sigma(\gamma, 2n) + \sigma(\gamma, np) + \sigma(\gamma, p)] dE = .70 \text{ Mev-b}$ $\sigma_{-2} = \int_0^{28} \sigma(E) E^{-2} dE = 1.82 \text{ mb-MeV}^{-1}$ $Q_0 = .94 \pm 0.13b$
$(\gamma, 2n)$ (444)		23.5		$.139 \pm .014$ ₀ ²⁸		
$(\gamma, n) + (\gamma, 2n) + (\gamma, np)$ (444)				$.586 \pm .058$ ₀ ²⁸		
$(\gamma, n) + 2(\gamma, 2n) + 3(\gamma, 3n) + (\gamma, np)$		17.5	11.5			

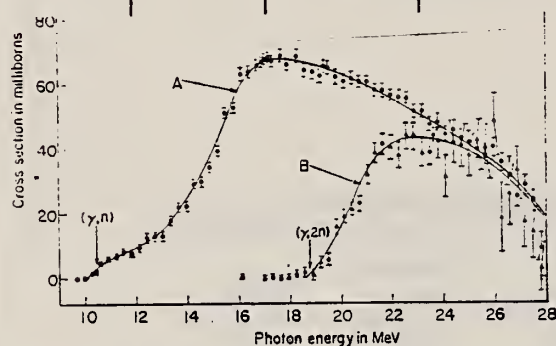


FIG. 1. Cross sections for Co from neutron yield data. Curve A consists of $\sigma(\gamma, n) + 2\sigma(\gamma, 2n) + \sigma(\gamma, np) + 3\sigma(\gamma, 3n)$ and was obtained from single-neutron counting data. Curve B consists of $2\sigma(\gamma, 2n) + 6\sigma(\gamma, 3n)$ and was obtained from double-neutron counting data.

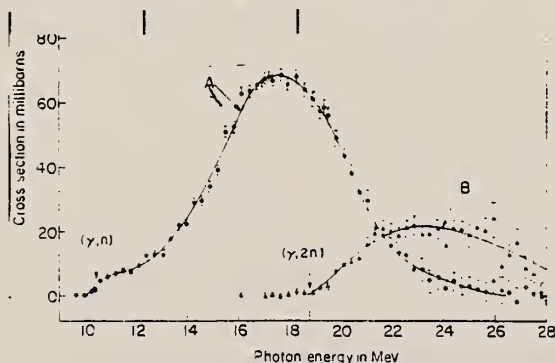


FIG. 2. Partial cross-section curves for Co. Curve A consists of $\sigma(\gamma, n) + \sigma(\gamma, np)$. Curve B consists of $\sigma(\gamma, 2n) + 3\sigma(\gamma, 3n)$.

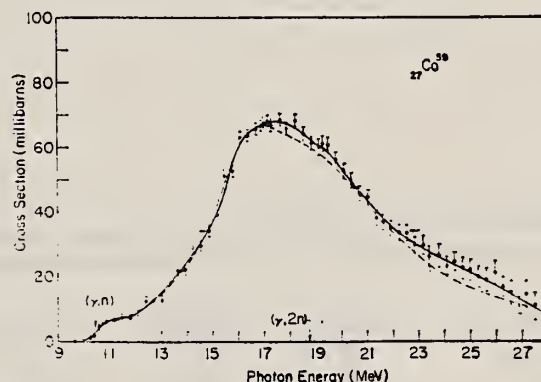


FIG. 3. The formation cross section, $\sigma(\gamma, n) + \sigma(\gamma, 2n) + \sigma(\gamma, np)$ for the compound nucleus Co^{58} . The solid curve represents an average line through the data points. The dashed curve is the sum of two Lorentz lines with parameters given in Table I.

(over)

TABLE I. Lorentz line and nuclear shape parameters for Co and V.

Element	σ_a (mb)	Γ_a (MeV)	E_a (MeV)	σ_b (mb)	Γ_b (MeV)	E_b (MeV)	Q_0 (b)	α (10^{-13} cm)	β (10^{-13} cm)	ϵ
Co ⁵⁹	40	3.75	16.5	43.4	7.0	19.25	0.94	5.53	4.68	0.355
V ⁵¹	41	3.60	17.5	46	6.5	20.25	0.66	4.40	5.15	0.336

TABLE II. Integrated cross sections and nuclear level density parameters. σ_{tot} includes estimated contributions for (γ, p) reactions.

Element	σ_{-1} (mb/MeV)	$0.00225A^{5/3}$ (mb/MeV)	α (MeV ⁻¹)	$\int_0^{28} \sigma dE$ (MeV-b)	$\int_0^{28} \sigma_{tot} dE + W$ (MeV-b)	$0.06 NZ/A$ (MeV-b)
Co ⁵⁹	1.82	2.014	5.49	0.586	0.87	0.879
V ⁵¹	1.56	1.564	6.18	0.557	0.84	0.758

Elem. Sym.	A	Z
Co	59	27
Ref. No.		NVB
63 Mi 5		25

Method Betatron; proton yield, angular distribution; scintillator;
ion chamber

Reaction	E or ΔE	E_0	Γ	$\int \sigma dE$	$J\pi$	Notes
$\text{Co}^{59}(\gamma, xp)$	Bremss. 22					Angular distribution: $Y(\theta) = a + b \sin^2 \theta (1 + p \cos \theta)^2$ where $a = 98 \pm 8$; $b = 3 \pm 10$ and $b/a = 0.0 \pm 0.2$. Yield ($E_p > 8$ MeV): $(1.8 \pm 0.1) 10^5$ protons/mole-r Yield ($3.7 < E_p < 14$): $(11 \pm 1) 10^5$

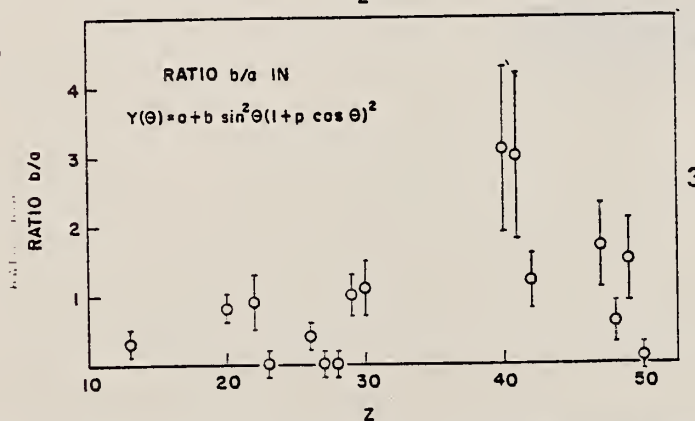
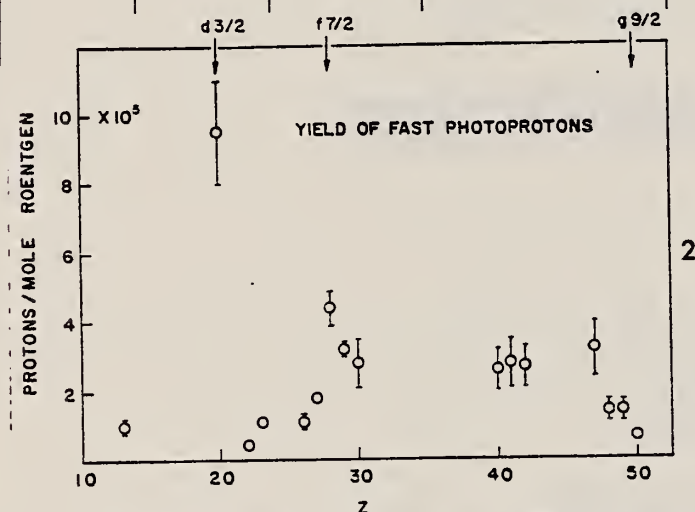


FIG. 2. The yields of fast photoprotons ($E_p > 8$ MeV) obtained from targets of various elements when irradiated with 22-Mev bremsstrahlung. The target thicknesses range from 331 to 572 mg/cm² (about 8 Mev for protons). The errors noted are statistical.

FIG. 3. The anisotropy coefficient b/a for fast photoprotons ($E_p > 8$ Mev) from 16 elements. The errors noted are statistical.

(over)

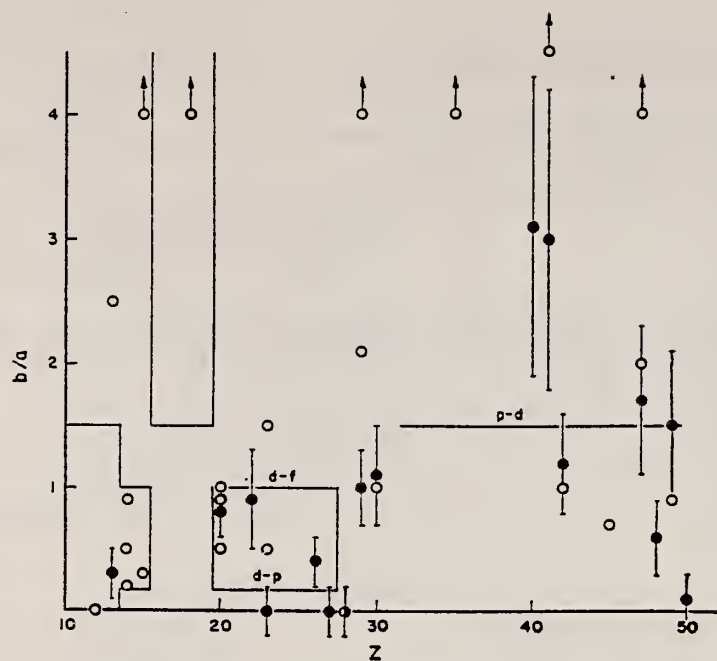


FIG. 4. The values of the fast photoproton anisotropy coefficient b/a found by the present authors (●) and other workers (○) in the region of the periodic table $10 < Z < 50$. Arrows indicate off-scale points. The references to the results of other workers are given in Table II. The demarcations are explained in the text.

REF. E.B. Bazhanov, A.P. Komar, A.V. Kulikov
Zhur. Eksp. i Teoret. Fiz. 46, 1497-1499 (1964)
Soviet Phys. JETP 19, 1014 (1964)

ELEM. SYM.	A	Z
Co	59	27

METHOD					REF. NO.		
Synchrotron					64 Ba 2		NVB
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	10-30	C	10-30	BF3-I		4PI

$$\int_0^{29} \sigma(\gamma, xn) dE = 701(\pm 13\%) \text{ MeV-mb}$$

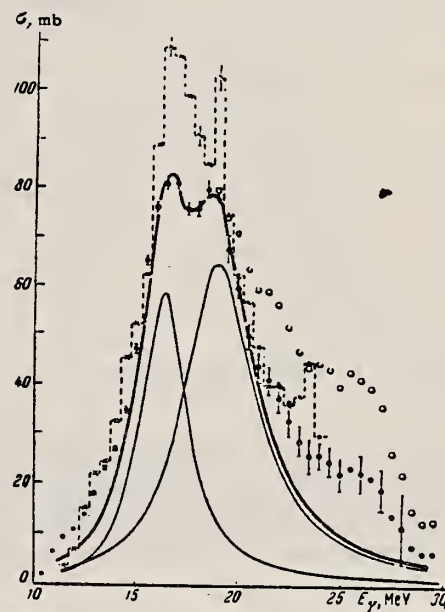


FIG. 2. Variation of photoneutron cross section with γ -ray energy for Co^{59} . Statistical errors are indicated. The light circles show the behavior of the cross section before correction is made for the multiplicity of neutrons.

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		egf
64 Ba 4		

METHOD			REF. NO.		
			64 Ba 4		
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G, XN	ABX	10-27	C	10-27	4PI

65 BA3 SAME DATA

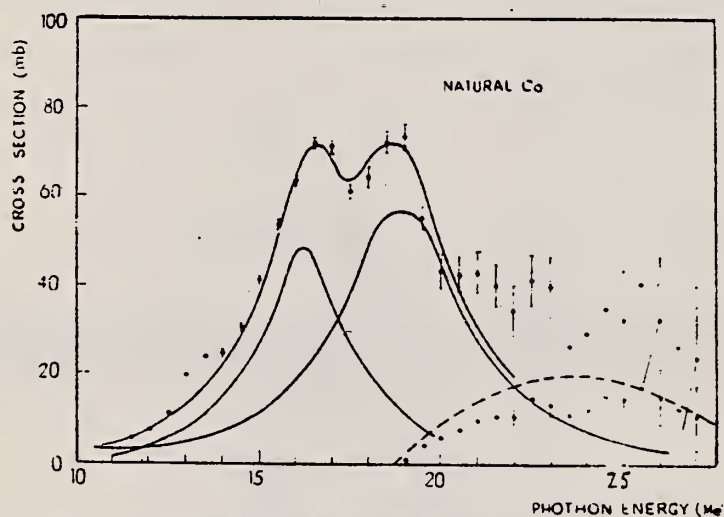


Fig. 1. - Total cross section for neutron photoproduction from Co^{59} .
The points represent the behaviour of $\sigma(\gamma, \text{Tn}) = \sigma(\gamma, n) + \sigma(\gamma, np) + 2\sigma(\gamma, 2n) + \dots$
The circles represent the values for $\sigma(\gamma, 2n)$ estimated by the statistical method, taking
as parameter of the density level the value $a = 6.5 \text{ MeV}^{-1}$.
The full line is the resultant of two Lorentzians corresponding to the parameters of Table I.
The dotted line represents the behaviour of $\sigma(\gamma, 2n)$ measured by Fultz et al. [6].

REACTOR					REF. NO.		
Van de Graaff; resonance fluorescence					64 Bo 1	172	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G.G	LFT	1-3	C	1 - 3	NaI-D		100
		(0.5 - 3.0)		(0.5 - 3.0)			

ABI

TABLE 1
Cases of observed resonance fluorescence

Nucleus multipol.	State (MeV)	Spin	Γ_0/Γ	$T(gw\Gamma_0^2/I^2)^{-1}$ (sec).	Mean lifetime T BCW (sec)	Mean lifetime T other (sec)	Ref.	Γ_0/Γ_w BCW
Co ⁵⁹	0.00	$\frac{1}{2}^-$						
(E2) ^a	1.19	($\frac{1}{2}$)	(1)	$8 \pm 2 \times 10^{-14}$	$11.5 \pm 5 \times 10^{-14}$		57	
[M1] ^a	1.46 1.48	[$\frac{1}{2}$]	?	$4 \pm 1.3 \times 10^{-13}$				$0.34\Gamma/\Gamma_0$
[M1] ^a	2.48 2.54	[$\frac{1}{2}$]	?	$7.5 \pm 2 \times 10^{-14}$				$0.04\Gamma/\Gamma_0$

ETHOD

REF. NO.

Synchrotron; $C^{12}(\gamma, n)$ monitor

64 Co 2

JOC

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
C.XN	ABY	THR - 80	C	80	BF3-I		4 PI

Table 1

Element	Yield (36) eV cm ² mol MeV	60 NZ/A (mb MeV)	Σ 0	Σ 0	Σ / Σ 0 0	E_m (MeV)	σ_m (mb)
²⁴ Cr	83 x 10 ⁻⁵	777	1.21	2.1	0.58	18.5	97
²⁵ Mn	108 x 10 ⁻⁵	818	1.52	2.33	0.65	18.5	114
²⁶ Fe	68 x 10 ⁻⁵	832	0.88	1.46	0.60	17.5	75
²⁷ Co	69 x 10 ⁻⁵	878	1.08	1.82	0.59	17.5	92
²⁸ Ni	44 x 10 ⁻⁵	879	0.55	1.07	0.51	18.5	56
²⁹ Cu	95 x 10 ⁻⁵	947	1.06	1.99	0.53	17.5	98
³⁰ Zn	88 x 10 ⁻⁵	975	0.94	1.68	0.56	17.5	86
³¹ Ga	130 x 10 ⁻⁵	1034	1.29	2.18	0.59	17.5	151
³² Ge	139 x 10 ⁻⁵	1064	1.35	2.29	0.59	17.5	158
³³ As	137 x 10 ⁻⁵	1109	1.22	2.18	0.56	17.5	127

$$\Sigma = \frac{\int_0^{30} \sigma(\gamma, xn) dE}{60 \text{ NZ/A}}$$

Table 2

Element	maximum yield (x 10 ⁻⁵)	$\sigma_{-1}(Tn)$	$\sigma_{-1}(Tn) \times \left[\frac{3}{4\pi^2} \frac{hc}{c^2} \left(\frac{A-1}{NZ} \right) A^{-\frac{2}{3}} \right]$
⁶ C	4.0	3.54	2.13
⁸ O	5.2	4.95	1.92
¹¹ Na	13.6	11.60	2.49
¹² Mg	10.0	8.81	1.73
¹³ Al	15.9	13.92	2.30
¹⁴ Si	11.6	9.96	1.55
¹⁵ P	19.8	17.56	2.32
¹⁶ S	9.5	6.55	1.07
¹⁹ K	19.6	17.90	1.61
²⁰ Ca	12.1	11.68	1.02
²⁴ Cr	86	61.6	3.56
²⁵ Mn	115	76.1	3.96
²⁶ Fe	71	50.3	2.55
²⁷ Co	94	63.5	2.94
²⁸ Ni	46	34.2	1.50
²⁹ Cu	102	72.3	2.96
³⁰ Zn	93	65.7	2.68
³¹ Ga	140	93.6	3.31
³² Ge	150	101.5	3.36
³³ As	151	99.3	3.12

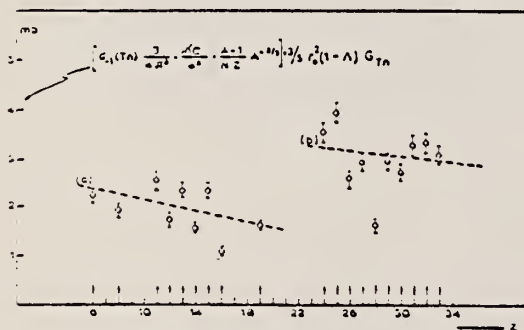


Fig. 2. Bremsstrahlung-weighted cross sections, $\sigma_{-1}(Tn)$, conveniently normalized, versus Z .

REF.

S. Costa, F. Ferrero, S. Ferroni and R. Malvano
Proc. Paris Conference 1034 (1964)

ELEM. SYM.

A

Z

Co

59

27

METHOD

100 MeV synchrotron

REF. NO.

64 Co 3

JDM

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	AB _I	THR-80	C	10-80	BF3-I		4PI

TABLE

ELEMENT	Yield (36 MeV) $\left(\frac{n \cdot cm^2}{mol \cdot MeV} \times 10^5\right)$	Σ_0^{30}	Σ_0^{80}	$\Sigma_0^{30} / \Sigma_0^{80}$	σ_{-1} (mb)
²⁴ Cr	83	1.21	2.1	0.58	62
²⁵ Mn	108	1.52	2.33	0.65	76
²⁶ Fe	68	0.88	1.46	0.60	50
²⁷ Co	89	1.08	1.82	0.59	64
²⁸ Ni	44	0.55	1.07	0.51	34
²⁹ Cu	95	1.06	1.99	0.53	72
³⁰ Zn	88	0.94	1.68	0.56	66
³¹ Ga	130	1.29	2.18	0.59	94
³² Ge	139	1.35	2.29	0.59	101
³³ As	137	1.22	2.18	0.56	100

$\Sigma_0^b = \frac{A}{60 NZ} \int_a^b \sigma(E) dE$ is the integrated cross section measured in units of the classical dipole $60 NZ/A$ mb. MeV.

METHOD

REF. NO.

NBS Monitor

[Page 1 of 2]

65 Ba 3

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	THR - 28	C	10-30	BF3-I		4PI

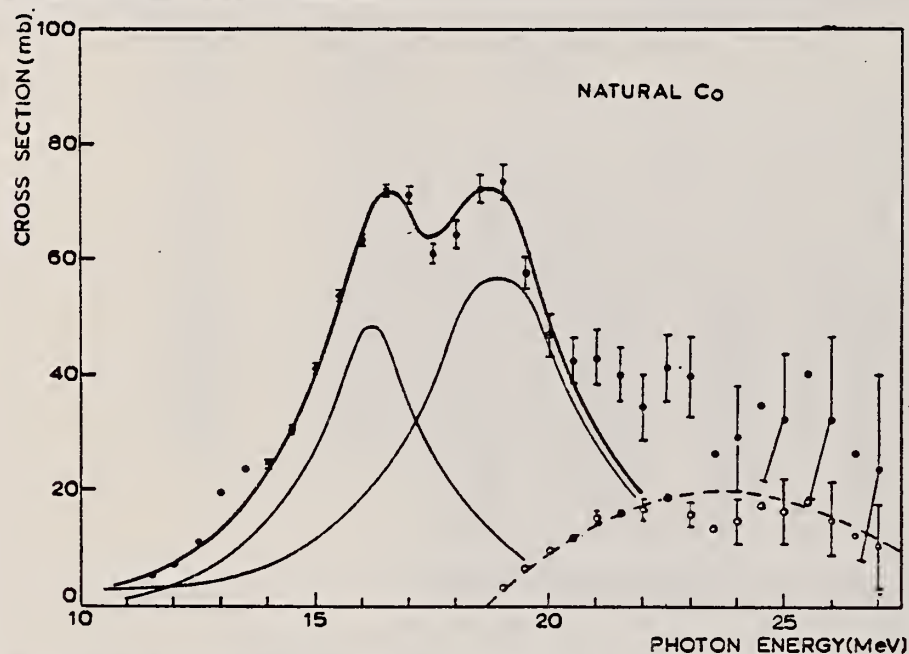


Fig. 1. Total photoneutron cross section for cobalt. The points represent the values of the $\sigma(\gamma, Tn) = \sigma(\gamma, n) + \sigma(\gamma, np) + 2\sigma(\gamma, 2n)$. The open circles represent the $\sigma(\gamma, 2n)$ values calculated with the statistical model taking $a = 6.5 \text{ MeV}^{-1}$ as found in sect. 4. The two Lorentz lines, having the parameters given in table 1, are such that their sum gives the heavier line drawn through the data points. The dashed line gives the $\sigma(\gamma, 2n)$ measured by Fultz *et al.* ⁹⁾.

TABLE 1
Lorentz line and nuclear shape parameters for cobalt obtained in the present work compared with those given by Fultz *et al.* ⁹⁾

E_m (MeV)	σ_m (mb)	Γ (MeV)	Q_0 (b)	s	a (fm)	b (fm)	Ref.
16.2	46	3.0	0.86	0.344	5.26	4.47	this work
18.8	57	4.6					
16.5	40	3.75	0.94	0.355	5.53	4.68	
19.25	43.4	7.0					⁹⁾

REF.

G. Baciú, G. C. Bonazzola, B. Minetti, C. Molino, L. Pasqualini,
and G. Piragino
Nuclear Phys. 67, 178 (1965)

ELEM. SYM.

A

Z

Co

59

27

METHOD

NBS Monitor

[Page 2 of 2]

REF. NO.

65 Ba 3

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	THR - 28	C	10-30	BF3-I		4PI

TABLE 2

Cross sections for Co, Ni, Cu and Ga

	E_m (MeV)	σ_m (mb)	$\int_0^x \sigma(E)dE$ (mb · MeV)	Ref.
Co ⁵⁹	16.9	130	750(24)	^{a)}
	16.75 19	110 103	709(25)	^{a)}
	17.5	68	725 ± 72(28)	^{a)}
	16.5 19	82 80	701 ± 91(29)	¹⁰⁾
	16.5 19	72 74	657 ± 89(28)	this work
			537 ± 34(24)	this work
			445 ± 48(24)	^{a)}
Ni	16.5	50	340(24)	¹¹⁾
	16.5	46 ± 1	313 ± 48(28)	this work
			276 ± 25(24)	this work
Ni ⁵⁸	18.5	60	330(24)	¹²⁾
		30	180(24)	¹³⁾
	20.5	21	160(24)	¹³⁾
	19.0	32	220 ± 30(32)	¹⁴⁾
Ni ⁶⁰	16.5	85	440(± 20 %)(24)	^{b)}
Cu	19.5	120	870(20)	^{a)}
			904(27)	¹⁵⁾
	17.2	126	930(27)	¹⁶⁾
	17	90	450 ± 15(19,6)	¹⁷⁾
	16.75	71 ± 7	745 ± 74(28)	¹⁸⁾
	17.0	86 ± 2	733 ± 105(28)	this work
			451 ± 18(20)	this work
Ga	16.5	115 ± 3	947 ± 98(28)	this work

σ_m is the peak value of the cross section, E_m is the peak energy and $\int_0^x \sigma(E)dE$ is the integrated cross section. The upper limit of the integration is indicated in parentheses.

^{a)} Value obtained subtracting the (γ , 2n) reaction contribution from the $\sigma(\gamma$, Tn).

^{b)} Value obtained by subtracting the Ni⁵⁸(γ , n)Ni⁵⁷ reaction contribution from the $\sigma(\gamma$, Tn) for natural nickel corrected for the (γ , 2n) reaction contribution.

6) S. C. Fultz *et al.*, Phys. Rev. 128 (1962) 2345

7) C. R. Hatcher, R. L. Bramblett, N. E. Hansen and S. C. Fultz, Nucl. Instr. 14 (1961) 337

8) R. Montalbetti, L. Katz and J. Goldenberg, Phys. Rev. 91 (1953) 659

9) P. A. Flurnoy, R. S. Ticle and W. D. Whitehead, Phys. Rev. 120 (1960) 1424

10) E. B. Bazhanov, A. P. Komar and A. V. Kulikov, JETP 46 (1964) 1497

REF.

J.M. Wyckoff, B. Ziegler, H.W. Koch, and R. Uhlig
Phys. Rev. 137, B576-94 (1965)

ELEM. SYM.

Co

A

59

Z

27

METHOD

Synchrotron; ion chamber monitor

REF. NO.

65 Wy 1

NVB

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, MU-T	ABX	10-35	-C	90	SCI-D		4 F I

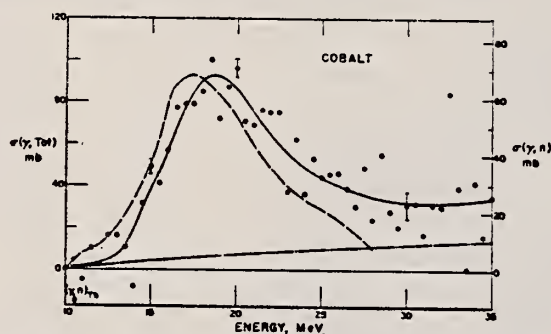


FIG. 23. Cobalt total photonuclear cross section. The solid line is drawn as the best approximation to the experimental points. The dashed line represents the $\sigma(\gamma, n)$ data of the Livermore group.

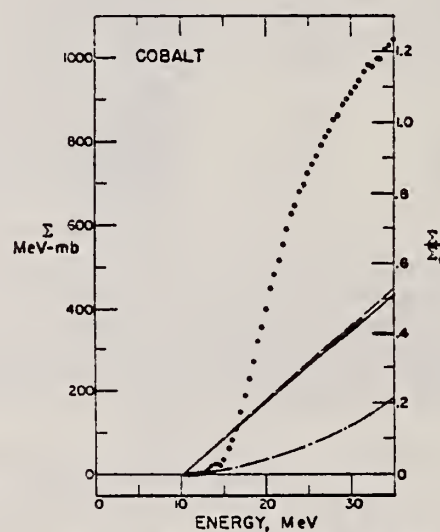


FIG. 24. Cobalt total photonuclear cross section integrated over energy. The solid, dashed, and dot-dashed lines have the same meaning as in Fig. 16.

REF.

F. W. K. Firk
Proc. Gatlinburg Conference 352 (1966)

ELEM. SYM.

A

Z

Co

59

27

METHOD

REF. NO.

66 Fi 2

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	SPC	THR-60	C	60	TOF-D	5-40	90

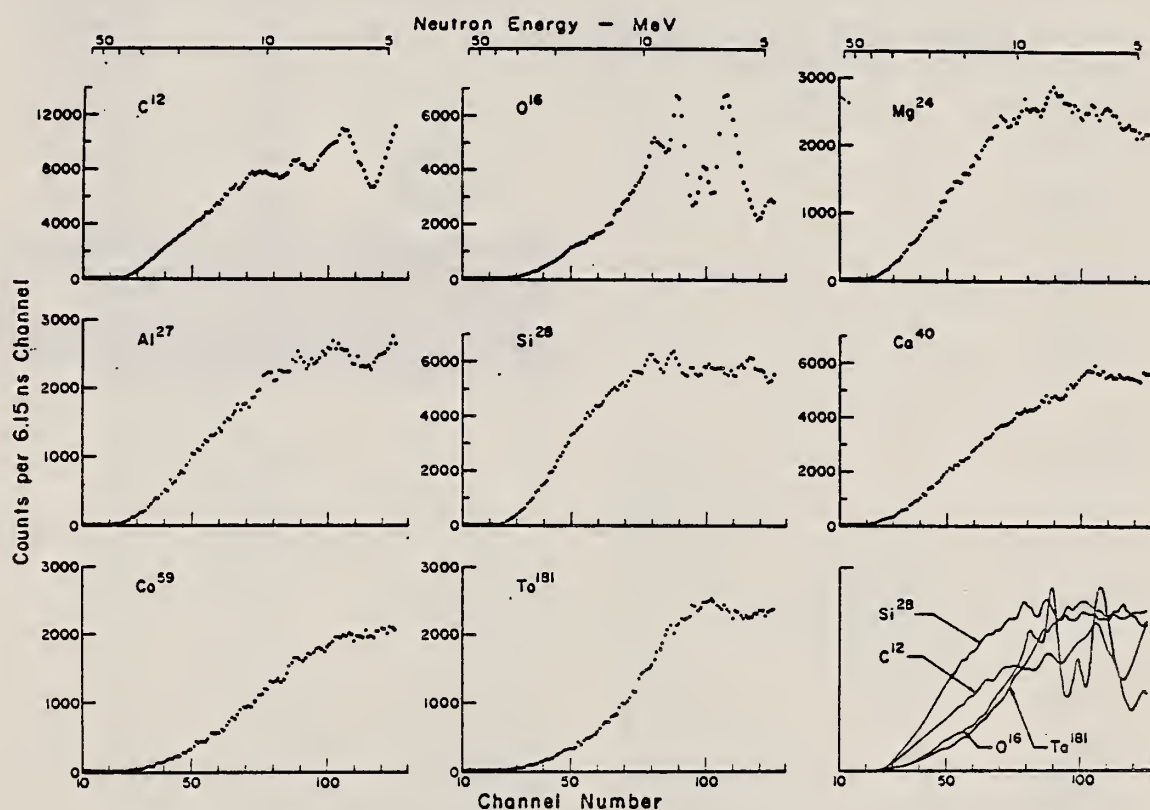


Fig. 1. Observed photoneutron time-of-flight spectra of C, O, Mg, Si, Ca, Co, V, and Ta.

W. B. Walters and J. P. Hummel
Phys. Rev. 150, 867 (1966)

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		JDM
66 Wa 1		

METHOD

Betatron

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,2P5N	RLY	THR-150	C	150	ACT-I		4PI

Measured isomeric yield ratios.

TABLE II. Summary of the results for the photoproduction of the Sc^{46} isomers (spins 2 and 6).

Target isotope and spin	Bremsstrahlung energy (MeV)	Fraction of yield to high-spin isomer
Sc^{46} ($I = \frac{7}{2}$)	50	0.21 ± 0.04
	75	0.21 ± 0.03
	175	0.20 ± 0.02
	223	0.18 ± 0.01
	264	0.17 ± 0.02
	300	0.21 ± 0.02
$\text{Fe}^{54,56}$ ($I = 0$) ^a	250	0.38 ± 0.02
Mn^{55} ($I = \frac{5}{2}$)	225	0.42 ± 0.04
	300	0.39 ± 0.02

^a It is assumed that most of the yield is due to reactions involving the two lightest isotopes present in natural iron (Fe^{54} and Fe^{56}).

¹⁹ The least-squares fitting program was supplied to us by G. Moscati. It was based on a program described in J. L. Need and T. E. Fessler, National Aeronautics and Space Administration Report No. NASA TND-1453, 1962 (unpublished).

REF. H. M. Gerstenberg and E. G. Fuller
NBS Tech. Note 416, June 1967

ELEM. SYM.	A	Z
Co	59	27

METHOD

REF. NO.	
67 Ge 2	HMG

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	THR-27	C	22,27	BF3-I		4PI

Table 7. Comparison of neutron yields. Yields are given in units of (neutron cm²/MeV nucleus) × 10⁻²⁸. The estimated uncertainties in Y and Y_c are of the order of 6% and 10%, respectively.

Element	E ₀	Y(E ₀)	UCRL Sacloy Va. NBS(Old)				UCRL Sacloy Va. NBS(Old)				Ref.
							Exp	Exp	Exp	Exp	
			Y _c				Y _c /Y				
Pb	27	103	86				0.83				26,30
	22	111	92	116			0.83	1.05			
Au	27	89	97				1.09				24,30,38
	22	92	98	88		115	1.07	0.96		1.25	
Ta	27	81	82	77			1.01	0.95			27,30,38
	22	85	79	80		113	0.93	0.94		1.33	
Ho	27	67	75				1.12				27,31,39
	22	69	77	82		103	1.12	1.19		1.49	
Ag	27	36									
	22	34.8									
Cu	27	14.4	13.2				0.92				28,30
	22	12.6	11.5	12.4			0.91	0.98			
Co	27	12.7	12.1				0.95				29,34
	22	10.6	9.9		13.5		0.94		1.27		
Ce	27	1.69		1.13	1.01			0.67	0.60		32,35
P	27	2.35			1.76				0.75		36
Al	27	1.92	1.62		1.38		0.84		0.72		25,37
O ¹⁸	27	0.54	0.42	0.48	0.42		0.78	0.89			16,32,37
C	27	0.50	0.35	0.33	0.46		0.70	0.66			25,32,33

(OVER)

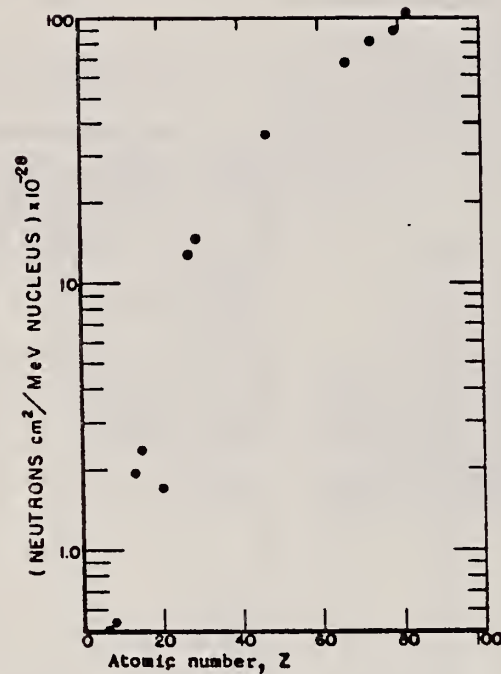


Fig. 31. Absolute neutron yield as a function of atomic number. The neutron yield from calcium ($Z = 20$) is particularly low in comparison with the other elements because its (γ, n) threshold is high compared to the mean energy of the giant resonance.

REF.

R. R. Hurst and D. J. Donahue
Nucl. Phys. A91, 365 (1967)

ELEM. SYM.

A

Z

Co

59

27

METHOD

Neutron capture gamma rays

REF. NO.

67 Hu 1

EGF

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	11	D	11	BF3-I		4PI

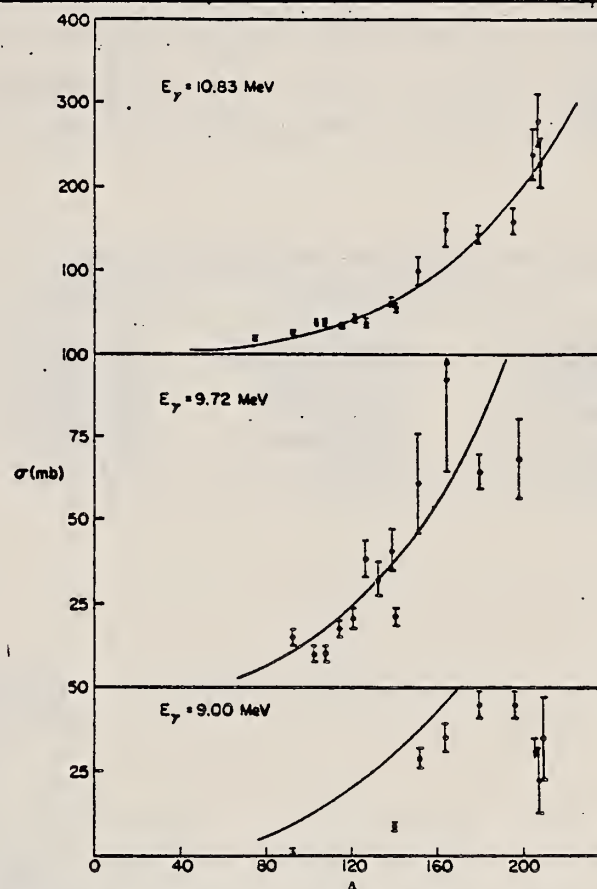


TABLE 1
Photoneutron cross sections (mb)

Fig. 1. Cross section (in mb) versus mass number of the target for gamma-ray energies of 9.00, 9.72 and 10.83 MeV. The solid lines are plots of eq. (1) in the text.

Target	7.72 MeV	9.00 MeV	9.72 MeV	10.83 MeV
⁵⁸ Co				9.0 ± 0.8
⁷⁶ As				20.4 ± 1.7
⁹² Nb		0.53 ± 0.10	14.6 ± 2.2	25.8 ± 2.1
¹⁰³ Rh			10.6 ± 1.7	38.8 ± 3.1
¹⁰⁷ Ag			10.0 ± 1.5	37.6 ± 2.9
¹⁰⁹ Ag			17.1 ± 2.6	33.3 ± 2.7
¹¹⁶ In			20.7 ± 3.1	42.5 ± 3.6
¹²¹ Sb			38.7 ± 5.8	38.8 ± 3.1
¹²³ Sb			31.7 ± 4.8	52.5 ± 3.8
¹²⁷ I			40.8 ± 6.5	63.0 ± 5.0
¹³³ Cs			21.5 ± 3.2	58.3 ± 4.1
¹³⁹ La		8.61 ± 0.86		
¹⁴¹ Pr			61.3 ± 14.7	102 ± 18
¹⁵¹ Eu		28.9 ± 3.2		
¹⁵³ Eu			92.2 ± 27.6	150 ± 20
¹⁶⁵ Ho		35.6 ± 4.3	65.0 ± 5.5	146 ± 12
¹⁸¹ Ta	4.14 ± 0.36	45.4 ± 3.7	68.4 ± 13.5	160 ± 15
¹⁹⁷ Au		44.5 ± 3.6		238 ± 29
²⁰⁸ Pb		< 34.3		280 ± 31
²⁰⁸ Pb		22.6 ± 11.3		226 ± 27
²⁰⁹ Bi		36.1 ± 12.0		

REF. H. Lichtblau and A. Goldmann Z. Physik <u>205</u> , 47 (1967)				ELEM. SYM.	A	Z	
				Co	59	27	
METHOD				REF. NO.			
				67 Li 1		egf	
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,2N	RLY	THR-54	C	35,54	ACT-I		4PI
G,3N							
G,4N							
G,XNYP							
ISOMER RATIO (G,N)							

ISOMER RATIO (G,N)

Table 2. Yield ratios at end point energies $E_m = 35$ and 54 MeV

Yield ratio	$E_m = 35$ MeV	$E_m = 54$ MeV
$Y[\text{Co}(\gamma, 2n)]/Y[\text{Co}(\gamma, n)]$	$(1.63 \pm 0.11) 10^{-1}$	$(1.86 \pm 0.13) 10^{-1}$
$Y[\text{Co}(\gamma, 3n)]/Y[\text{Co}(\gamma, n)]$	$(1.24 \pm 0.12) 10^{-3}$	$(6.34 \pm 0.25) 10^{-3}$
$Y[\text{Co}(\gamma, 4n)]/Y[\text{Co}(\gamma, n)]$	below threshold	$(1.02 \pm 0.08) 10^{-4}$
$Y[\text{Co}(\gamma, x)^{56}\text{Mn}]/Y[\text{Co}(\gamma, n)]$	$(3.7 \pm 0.7) 10^{-5}$	$(1.26 \pm 0.05) 10^{-3}$
$Y_m/(Y_m + Y_s)$	$(5.70 \pm 0.20) 10^{-1}$	$(5.77 \pm 0.20) 10^{-1}$
$Y[\text{Co}(\gamma, n)]/Y[C(\gamma, n)^{11}\text{C}]$	16.1 ± 1.3	13.5 ± 1.1

Table 3. Values of σ_γ in mb calculated from the yield ratios of Table 2, based on the $^{12}\text{C}(\gamma, n)$ cross section of BARBER *et al.*²⁵ (see also footnote *). An additional error of 4.5%, due to uncertainties in the calibration of the methane counter²¹, which applies equally to all listed values of σ_γ , is not included in the quoted errors

E_m	Reaction				
	(γ, n)	$(\gamma, 2n)$	$(\gamma, 3n)$	$(\gamma, 4n)$	$(\gamma, x)^{56}\text{Mn}$
35 MeV	28.3 ± 1.0	4.6 ± 0.2	$(3.5 \pm 0.3) 10^{-2}$	—	$(1.1 \pm 0.2) 10^{-3}$
54 MeV	31.7 ± 1.2	5.9 ± 0.3	$(2.0 \pm 0.15) 10^{-1}$	$(3.2 \pm 0.3) 10^{-3}$	$(4.0 \pm 0.3) 10^{-3}$

* Reference to the $C(\gamma, n)$ cross section measured by COOK *et al.*²⁸ has the effect of increasing the values listed in table 3 by 8% at $E_m = 35$ MeV and by 10% at $E_m = 54$ MeV.

²¹Krämer, K., H.v. Buttler, A. Goldmann, B. Huber:
Z. Physik 207, 1 (1967).

²⁶Howerton, R.J.: UCRL-Report 5573 (1961).

REF.

J. M. Loiseaux, J. M. Maison, and M. Langevin
J. de Physique 28, 11 (1967)

ELEM. SYM.

A

Z

Co

59

27

METHOD

REF. NO.

67 Lo 1

JOC

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G/	ABX	14-32	C	34	NAI-D		DST

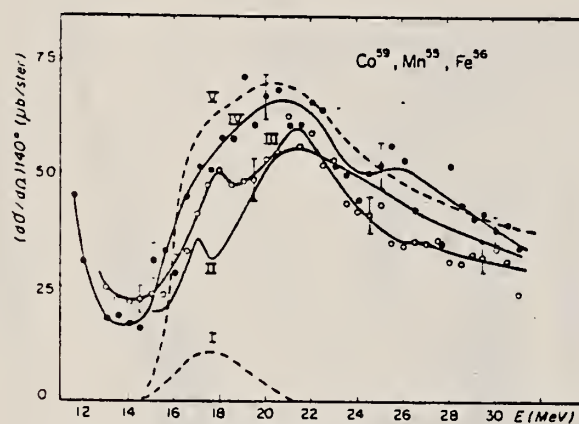


FIG. 10.

Sections efficaces différentielles de diffusion à 140° pour ^{55}Mn (courbe II), ^{56}Fe (courbe III), ^{59}Co (courbe IV).

Section efficace de diffusion tenseur (courbe I) et section efficace de diffusion scalaire - tenseur (courbe V) calculées avec les paramètres de Fultz et al. [16] pour ^{59}Co .

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		egf
68 Al 1		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, G	LFT	0 - 1 (1.19)	C	4	SCD-D	0-3	130

Angle greater than 90° for all measurements.

SELF-ABSORPTION

TABLE I
Direct and absorption measurements of resonance fluorescence

Nucleus	E_r (MeV)	J_r	Γ_0/Γ	$gW\Gamma_0/\Gamma$ (meV)	Error (%)	This work Γ_0 (meV)	Other work Γ_0
⁵⁵ Mn	0.000	$\frac{1}{2}^-$					
	1.527	$(\frac{1}{2}^-)$	0.9	5.2	25	8-12	
				abs a)	40	8.0	
	1.884	?	0.82 b)	41	25	50/gW	
				abs a)	10	55/g	
	2.197	?	(0.8) c)	17	25	21/gW	
				abs	20	17/g	
	2.252	?	(0.9) c)	17	25	19/gW	
				abs	20	13/g	
	2.365	?	?	3.5	36	(2-6) Γ/Γ_0	
⁵⁹ Co	2.564	?	(1.0)	50	25	50/gW	
				abs a)	20	61/g	
	2.751	?	?	6.7	42	6.7(Γ/Γ_0)/gW	
	0.000	$\frac{7}{2}^-$					
	1.187	$(\frac{3}{2}^-)$	(1.0)	6.8	25	7.5	0.33(E2) ^{d)}
				abs	25 a)	12	
⁶³ Cu		$(\frac{3}{2}^-)$	(1.0)	6.8	25	(5.4-6.5)	0.27(E2)
				abs	25 a)	9.6	
	0.000	$\frac{3}{2}^-$					
⁶⁷ Ga	1.414	$\frac{1}{2}^-$	?	1.6	30	(1.1-1.7) Γ/Γ_0	
	1.551	$\frac{1}{2}^-$	?	1.7	37	(1.7-2.5) Γ/Γ_0	0.1(E2) e)
	0.000	$\frac{1}{2}^-$					
⁷⁵ As	0.872	$(\frac{1}{2}^-)$	0.95	1.1	35	0.8/W	
	1.107	$(\frac{1}{2}^-)$	0.95	8.0	20	8.4/W	
	0.000	$\frac{1}{2}^-$					
	0.86	?	?	1.7	20	1.7 $\Gamma/gW\Gamma_0$	
⁸⁹ Y	1.07	?	?	2.6	30	2.6 $\Gamma/gW\Gamma_0$	
	1.35	?	?	3.6	20	3.6 $\Gamma/gW\Gamma_0$	
	0.000	$\frac{1}{2}^-$					
	1.51	$\frac{1}{2}^-$	(1.0)	52 a)	30	28	0.37(E2) f)
				abs a)	15	22	

a) Measured with NaI.

b) Ref. ¹⁴⁾.c) Measured with a Ge(Li) detector to $\pm 10\%$.d) Ref. ¹³⁾.e) Ref. ¹⁴⁾.f) Ref. ²³⁾.¹³ D.G. Alkhazov, K.I. Erokhina and I.K. Lemberg, Izv.Akad.Nauk.SSSR(ser.fiz.)
28 (1964) 1667.¹⁴ B.G. Harvey, J.R. Meriwether and A.Bussiere, Nucl. Phys. 70 (1965) 305.²³ G.A. Peterson and J.Alster, Phys.Rev. 166 (1968) 136.²⁴ N. Nath, M.A. Rothman, D.M. Van Patter and C.E. Mandeville, Nucl. Phys. 13
(1959) 74.

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$G,XN	SPC	THR-85	C	85	CCH	1-15	135

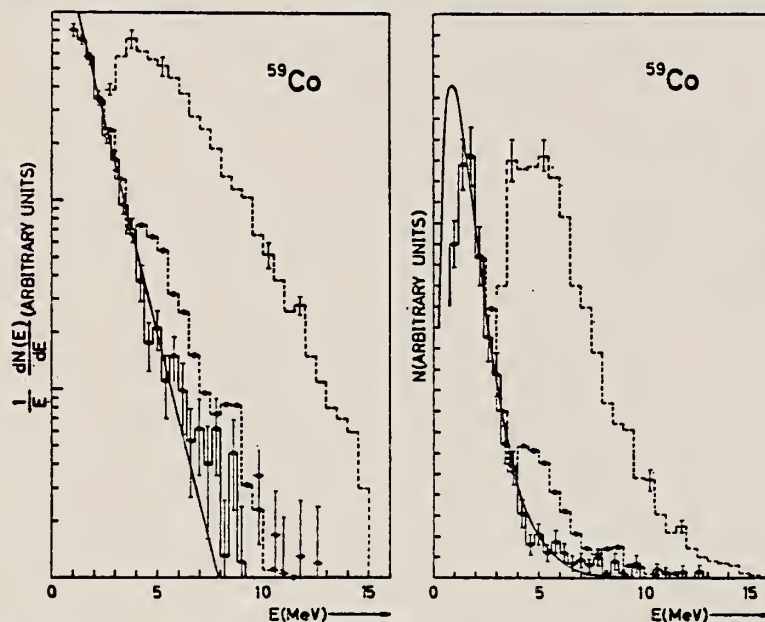
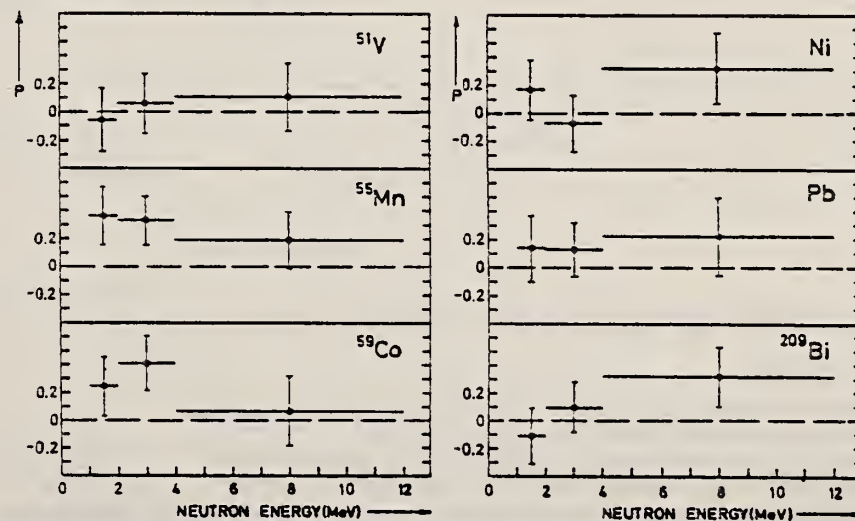


Fig. 5. Energy spectrum of photoneutrons from ^{59}Co compared with the spectrum of photoprotons for $E_{\gamma \text{ max}} = 24 \text{ MeV}$ of ref. ¹¹ (dashed histogram). The dotted histogram represents the photoneutron spectrum deduced by Emma *et al.* ¹⁴ at 90° with $E_{\gamma \text{ max}} = 30 \text{ MeV}$ (open circles). The spectra are normalized to the maximum value of N . The full line has the same meaning as in fig. 2.

¹⁶V. Emma, C. Milone, A. Rubbino, S. Jannelli and Mezzanares, Nuovo Cim. 22, 135 (1961).



ELEM. SYM.	A	Z
Co	59	27
REF. NO.		
68 Rh 1		egf

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, XN	NOX	THR-48	C	48	ACT- I		4PI

TABLE I. ⁶⁰Co isomer ratios.

Reaction	Reference	Bremsstrahlung endpoint energy (MeV)	Experimental isomer yield (ground-state/total)
⁶⁰ Co(γ,n)	7	30	0.56±0.02
	8	30	0.55±0.02
	9	35	0.43±0.02
	This work	43	0.43±0.03
	9	54	0.43±0.02
⁶⁰ Ni(γ,np)	10	68	0.38±0.02
	This work	48	0.68±0.03

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	SPC	11-85	C	85	CCH-D		135

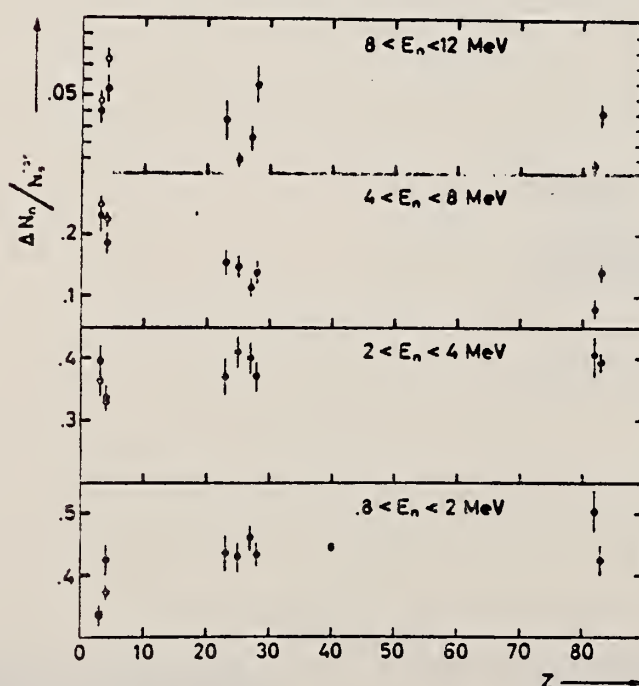


Fig. 1. - Percentage of the photoneutrons emitted at 135° , in the respective energy interval as a function of Z , by a γ -ray bremsstrahlung beam with $E_{\gamma \max} = 85$ MeV. The open circles represent the values obtained at 60° for ${}^7\text{Li}$ and ${}^9\text{Be}$.

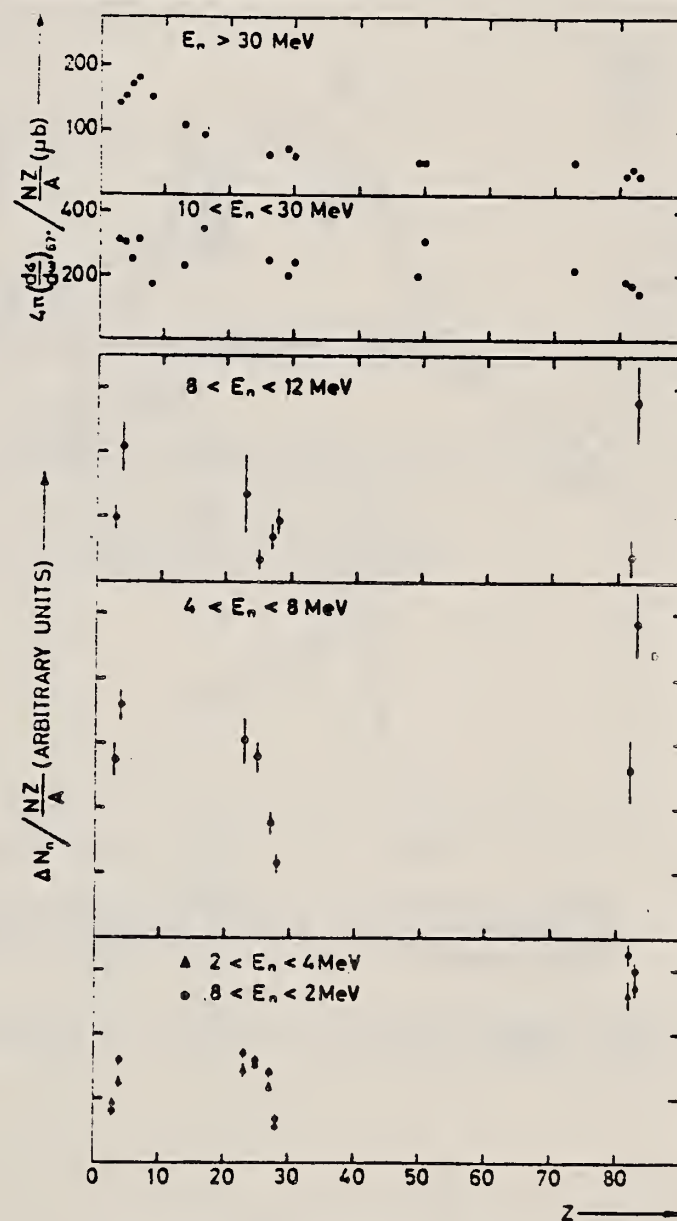


Fig. 2. - Number of photoneutrons emitted at 135° , normalized to the sum rule factor NZ/A , as a function of Z . In the upper part is reported the effective cross section divided by NZ/A for photoproduction of fast neutrons by 55-85 MeV bremsstrahlung photons as deduced by Kaushal *et al.* [1].

¹ N.N. Kaushal *et al.*, Phys. Rev. 175, 557 1330 (1968).

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	ABX	10-30	C	10-30	BF3-I		4PI

450

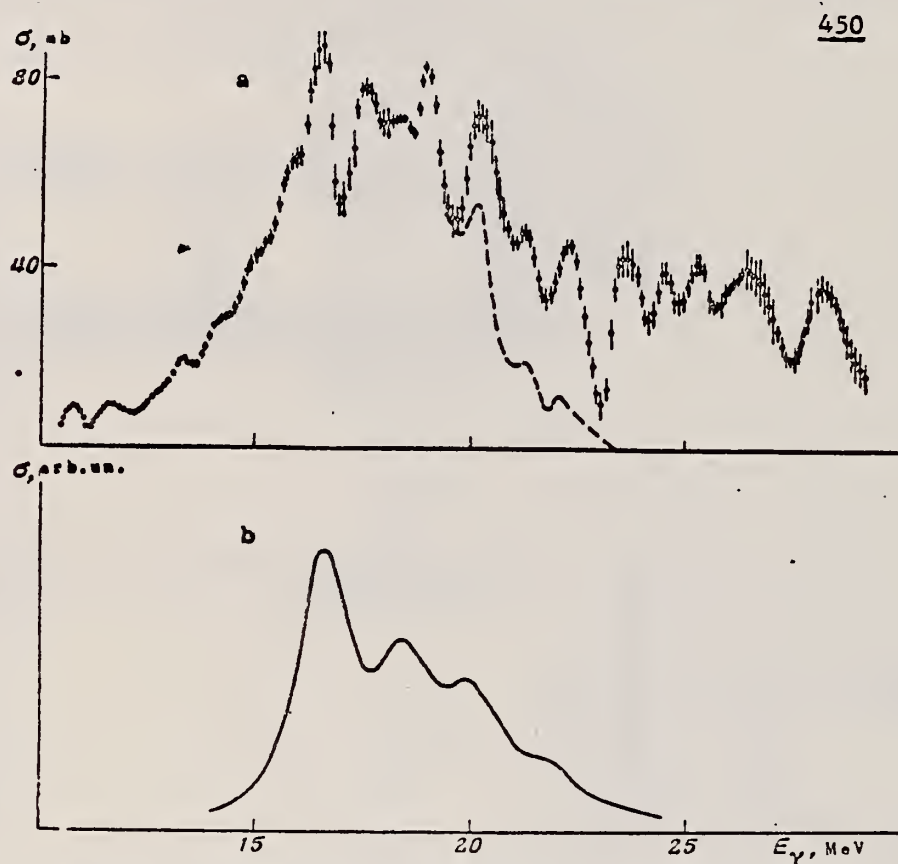


Fig.3. a - The $(\gamma, n) + (\gamma, 2n)$ cross section for ^{59}Co ,
b - absorption cross section implied by the collective
dynamic model⁶.

⁶M.G. Huber, M. Danos, H.J. Weber & W. Greiner, Phys. Rev.
155, 1073 (1967).

(over)

Characteristics of the Photonutron Cross Sections (in MeV-mb)

Nucleus	Integral cross sections*				Center of gravity $\sigma(\gamma n) + \sigma(\gamma, 2n)$, MeV	Refs.	Dipole sum rule $6NZ/A$, MeV-mb
	$\sigma(\gamma n) + 2\sigma(\gamma, 2n)$	$\sigma(\gamma n) + \sigma(\gamma, 2n)$	$\sigma(\gamma n)$	$\sigma(\gamma, 2n)$			
²⁴ Mg	820 (30)	600 (30)	380 (30)	220 (30)	21,3	Our work	760
	670 (28)	560 (28)	450 (28)	110 (28)		[9]	
	590 (24)					[10]	
	560 (25)					[11]	
⁵² Cr	950 (30)	740	530 (30)	210 (30)	20,4	Our work	775
	600 (24)					[10]	
⁵⁹ Co	1030 (30)	740 (30)	450 (30)	290 (30)	20,2	Our work	880
	730 (28)	590 (28)	450 (28)	140 (28)		[9]	
	870 (29)					[12]	
	840 (25)					[13]	
	660 (28)					[14]	
	630 (25)					[11]	

*The upper integration limits are given in parentheses.

9. S.C.Fultz, R.L.Bramblett, I.T.Caldwell, N.E.Hansen & C.P.Jupiter, Phys. Rev. 128, 2345 (1962).
10. J.Goldemberg & L.Katz, Canadian J. Phys. 32, 49 (1954).
11. B.Nathans & J.Halpern, Phys. Rev. 93, 437 (1954).
12. E.B.Bazhanov, A.P.Komar & A.V.Kulikov, Zh. Eksperim. i teor. fiz. 46, 1497 (1964). (Trans. Soviet Physics - JETP.)
13. P.A.Flournoy, R.S.Tickle & W.D.Whitehead, Phys. Rev. 120, 1424 (1960).
14. G.Baciu, G.C.Bonazzola, B.Minetti, C.Molino, L.Pasqualini & G.Piragino, Nuclear Phys. 68, 178 (1965).

REF.	G. Baci, D. Catana, C. Deberth, C. Iliescu, B. Carstoiu Nucl. Phys. <u>A167</u> , 177 (1971)			ELEM. SYM.	A	Z
				Co	59	27
METHOD				REF. NO.		
				71 Ba 1		egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,XN	251†	ABX	10-22	C	10-22	BF3-I	4PI

TABLE 1
Results

E_m (MeV)	σ_m (mb)	$\int_0^x \sigma(w)dw$ (mb · MeV)	Ref.
16.9	130	750 (24)	¹⁸⁾
16.75 19	110 103	709 (25)	¹⁹⁾
17.5	68	725 ± 72 (28)	²⁰⁾
16.5 19	82 80	701 ± 91 (29)	²¹⁾
16.5 19	72 74	657 ± 89 (28)	²²⁾
17.44 19.29	120.0 102.9	598.7 ± 0.9 (22)	this work

Here σ_m is the peak value of the cross section, E_m is the peak energy and $\int_0^x \sigma(w)dw$ is the integrated cross section. The upper limit of the integration is indicated in parenthesis.

- ¹⁶M.G. Huber, M. Danos, H.J. Weber and W. Greiner, Phys. Rev. 155 (1967) 1073
- ¹⁸R. Montalbetti, L. Katz and J. Goldemberg, Phys. Rev. 91 (1953) 659
- ¹⁹P.A. Flurnoy, R.S. Ticle and W.D. Whitehead, Phys. Rev. 120 (1960) 1424
- ²⁰S.C. Fultz, R. L. Bramblett, J. T. Caldwell, N.E. Hansen and C.P. Jupiter, Phys. Rev. 128 (1962) 2345
- ²¹E.B. Bazhanov, A.P. Komar and A.V. Kulikov, JETP (Sov. Phys.) 46 (1964) 1497
- ²²G. Baci, G.C. Bonazzola, B. Minetti, C. Molino, L. Pasqualini and G. Piragino, Nucl. Phys. 67 (1965) 178

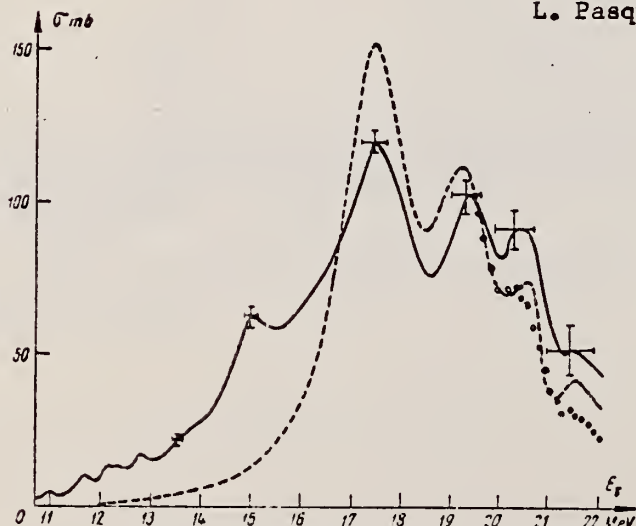


Fig. 1. Least-structure solution for $^{60}\text{Co}(\gamma, n)$ cross section (full line). The statistical errors and resolution are shown at representative energies (at cross-section peak values). The points at higher energies represent an estimate for multiplicity correction. The dashed line illustrates the calculation by using the appropriate parameters ¹⁶⁾.

REF.

G. J. Kumbartzki, Ung Kim and Ch. K. Kwan
Nucl. Phys. A160, 237 (1971)

ELEM. SYM.

A

Z

Co

59

27

METHOD

REF. NO.

71 Ku 2

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,SPL	ABY	THR-999	C	999	ACT-I		4PI

 $\sigma_q(A,Z) = K \exp [PA - R(A - SZ + TZ^2)^2]$, cross section per equivalent quantum.

999 = 1.5 GEV

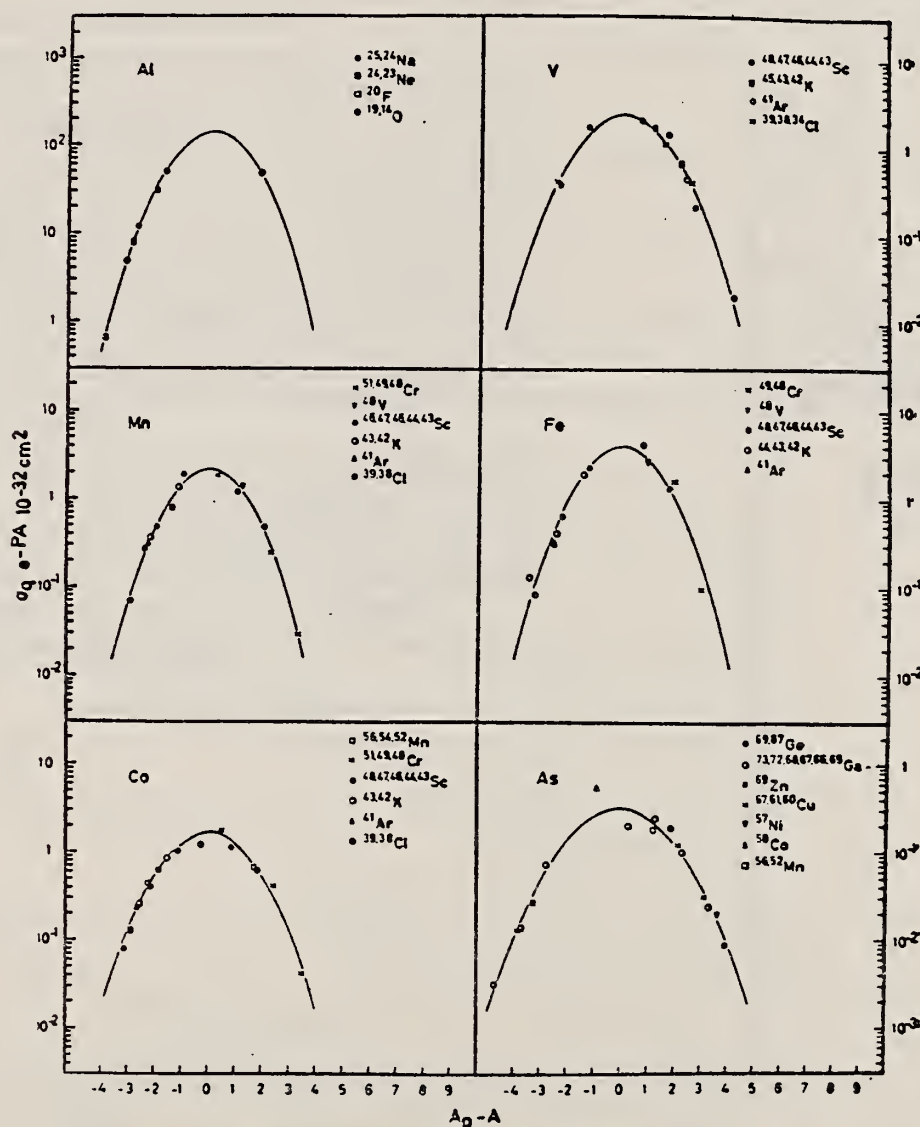


Fig. 4. Yield distributions from various targets with bremsstrahlung of 1.5 GeV.

[over]

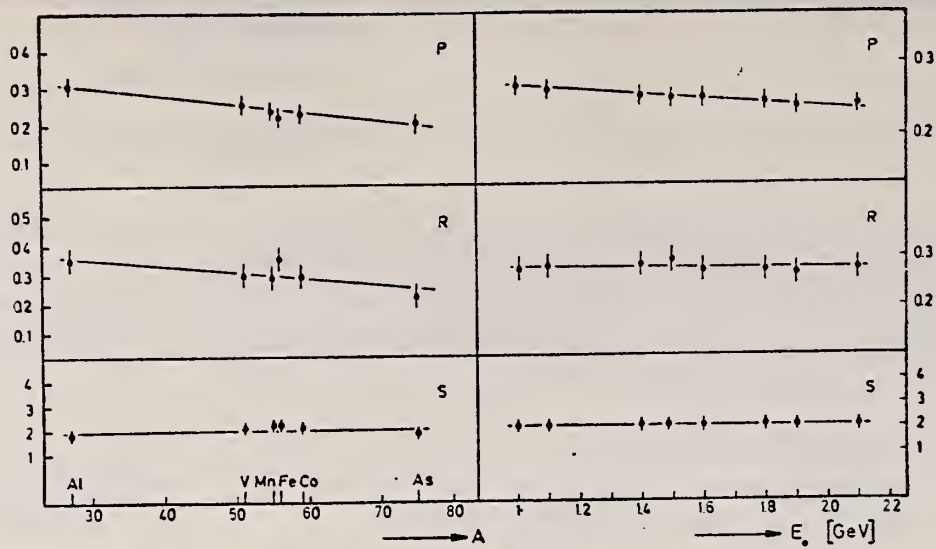


Fig. 6. Behaviour of the parameters P , R and S as functions of A and E_0 .

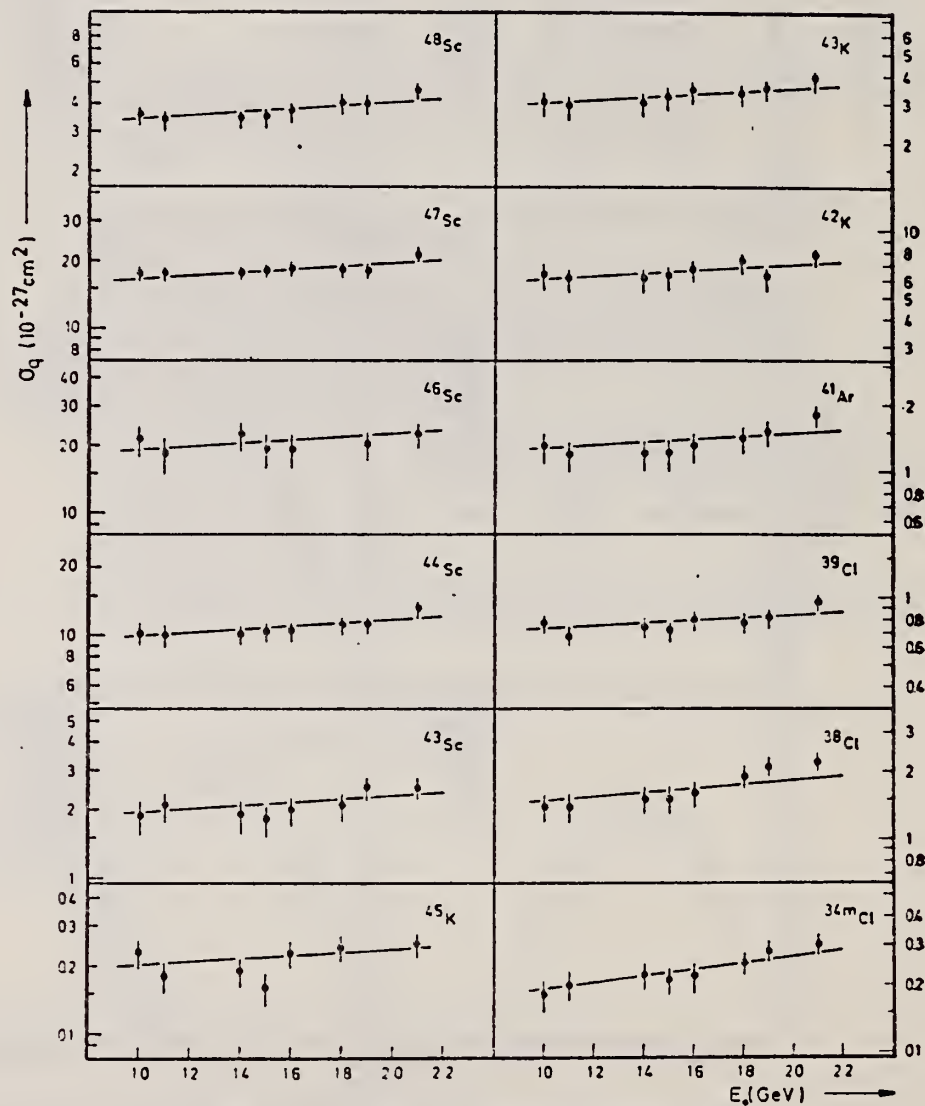


Fig. 5. Yields of spallation products using vanadium targets.

METHOD

REF. NO.

71 Sa 1

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	10-68	C	10-68	AGI-I		4PI

Nippon Kagaku Zasshi. 92, 164~168(1971)

The Yields of Radioactivities Induced by (γ, n) Reactions with Bremsstrahlung up to 68 MeV

by Tatsuya SAITO

The (γ, n) yields of 12 target nuclides have been measured at 10, 13, 16, 30, 45 and 68 MeV bremsstrahlung by observing the induced activities.

The energy dependence of the yields has been investigated extensively in the same way as in the previous work at 20 MeV bremsstrahlung.

In the case of heavy nuclides, the yields rise greatly as a function of maximum bombarding energy up to 20 MeV, and rise gradually from 20 MeV up to 68 MeV. However, in the case of light nuclides, the yields rise greatly up to 30 MeV, because the neutron separation energies of light ones are larger than those of heavy ones, and the bremsstrahlung spectrum covers the giant resonance and so the yields rise gradually from 30 MeV up to 68 MeV.

The yields have approximately been estimated from the parameter of the giant resonance, that is the peak cross section and the half width, in order to compare with the experimental data. As a result, the experimental data of light nuclides and heavy ones are nearly in agreement with the estimated data of Nathans et al., Johns et al. and Montalbetti et al., but those of medium weight ones are relatively lower values.

Department of Chemistry, Faculty of Science, Tohoku University;
Katahira-cho, Sendai-shi, Japan

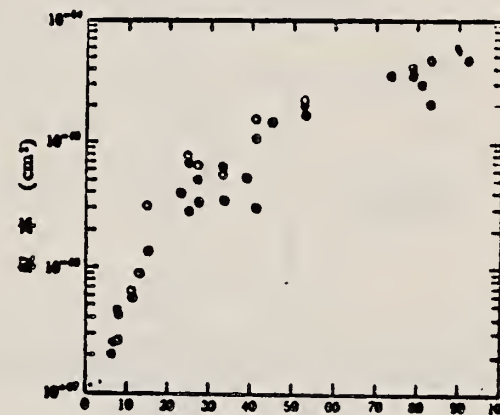


図 4 (γ, n) 反応の収率の比較
●: 実験値, ⊕: Johns ら,
⊙: Nathans ら, ○: Montalbetti ら

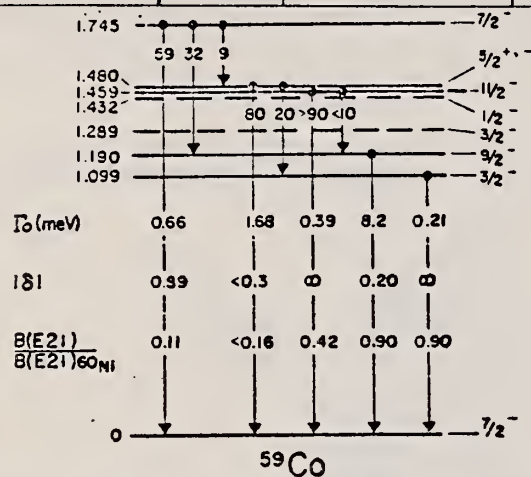
METHOD

REF. NO.

71 Sw 3

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	1-5	C	5	SCD-D		DST



15 LEVELS, J-PI

Fig. 4. Decay scheme of the first five levels observed in ^{59}Co . Also given are the ground state transition widths, the amplitude mixing ratios and the $B(E2\downarrow)$ values relative to that for the 1330 keV state of ^{60}Ni .

TABLE 1
Properties of the observed levels

Level (keV)	J^π	$W(\theta)g \Gamma_0^2/\Gamma^*$ (meV)	Γ_0/Γ^*	Γ_0 (meV)		$|\delta|$	
				present	others	present	others
1098.7 ± 0.5	$\frac{1}{2}^-$	0.11 ± 0.02	1.0	0.21 ± 0.04	$0.12 \pm 0.03^*)$		
1189.6 ± 0.5	$\frac{3}{2}^-$	10.25 ± 0.50	1.0	8.2 ± 0.4	$8.2 \pm 1.0^*)$	0.16 ± 0.09	$0.20^*)$ $0.25 \pm 0.05^*)$
1458.8 ± 0.3	$\frac{1}{2}^-$	$0.62 \pm 0.06^*)$	> 0.9	0.39 ± 0.04	$0.44 \pm 0.08^*)$		
1480.4 ± 0.3	$\frac{1}{2}^+$	$1.06 \pm 0.11^*)$	0.8	1.68 ± 0.17		< 0.35	
1745 ± 1	$\frac{7}{2}^-$	0.39 ± 0.12	0.59	0.66 ± 0.19			$0.89 \pm 0.35^*)$
2479 ± 1		$11.5 \pm 0.5^*)$	> 0.9				
2783 ± 1		15.0 ± 1.0					
2825 ± 1	$(\frac{1}{2}^-)^*$	4.8 ± 0.6					
2966 ± 1		2.7 ± 0.8					
3328 ± 2		6.2 ± 1.2					
3625 ± 2		8.5 ± 2.2					
3667 ± 2		16.6 ± 2.4					
3954 ± 3		12.3 ± 2.4					
4303 ± 3		17.1 ± 4.7					
4467 ± 3		42.2 ± 6.3					

^{a)} Errors given in this column are statistical and do not include an estimated error of 10 % on $N(E_\alpha)$.

^{b)} See ref. ⁴⁾.

^{c)} See ref. ⁵⁾.

^{d)} Booth *et al.* ²²⁾ observed lines at about 1.47 and 2.5 MeV. The cross sections they give agree well with the values we obtained for the combined 1.459 and 1.480 MeV levels and for the 2.479 MeV level respectively.

^{e)} See ref. ²⁰⁾.

³⁾ R. Nordhagen, B. Elbek and B. Herskind, Nucl. Phys. A104, 353 (1967).

⁴⁾ K. L. Coop, I. G. Graham and E. W. Titterton, Nucl. Phys. A150, 346 (1970).

²⁰⁾ M. Mazari, A. Sperduto and W. W. Buchner, Phys. Rev. 107, 365 (1957).

²²⁾ E. C. Booth, B. Chasan and K. A. Wright, Nucl. Phys. 57, 403 (1964).

ELEM. SYM.	A	Z
Co	59	27

METHOD			REF. NO.		
			72 Ke 4		hmg
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G ₁ A	RLY	7-32	C	32	DST

TABLE 3. Observed angular distribution parameters for 32 MeV electron energy

Element	A_0	A_1/A_0	A_2/A_0
Ti	7.03 ± 0.15	0.073 ± 0.052	-0.286 ± 0.073
V	2.58 ± 0.06	0.037 ± 0.042	-0.126 ± 0.069
Fe	10.22 ± 0.30	0.006 ± 0.043	-0.333 ± 0.072
Co	6.80 ± 0.20	0.022 ± 0.048	$+0.016 \pm 0.077$
Ni	15.95 ± 0.49	0.051 ± 0.048	-0.213 ± 0.074
Cu	8.37 ± 0.28	0.076 ± 0.056	-0.035 ± 0.081
Zn	17.87 ± 0.61	0.004 ± 0.045	-0.270 ± 0.073
Ag	0.39 ± 0.01	0.115 ± 0.049	$+0.093 \pm 0.074$

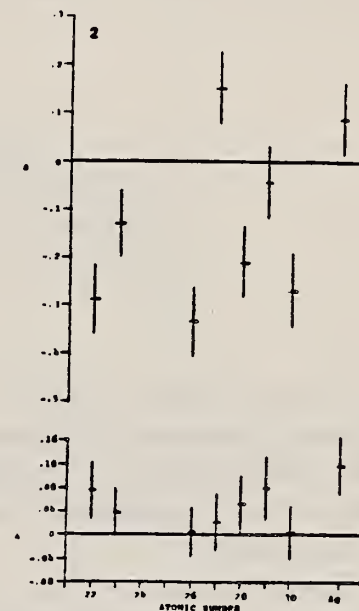


FIG. 2. Angular distributions for 32 MeV electron energy.

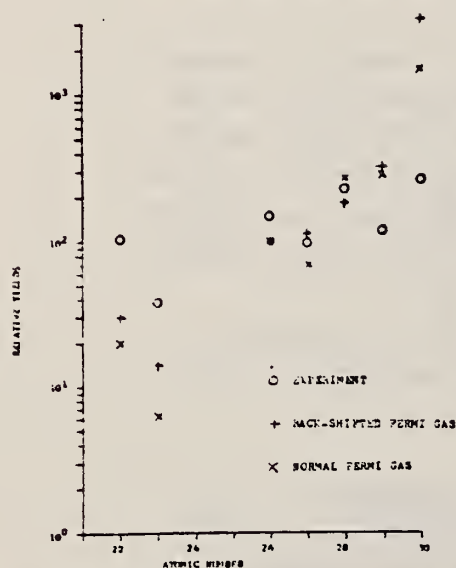


FIG. 13. Experimental and theoretical relative photo-alpha yields for 32 MeV electron beam energy.

REF.

R.A. Alvarez, B.L. Berman, F.H. Lewis, P. Meyer
PICNS-73, Vol. I, p. 547 Asilomar

ELEM. SYM.

A

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Co

59

27

METHOD

REF. NO.

73 A1 7

hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	10- 37	D	10- 37	BF3-I		4PI
G,2N	ABX	17- 37	D	17- 37	BF3-I		4PI
G,3N	ABX	29- 37	D	29- 37	BF3-I		4PI

525+

We report here the results of measurements of the ^{59}Co photoneutron cross sections with nearly monoenergetic photons obtained simultaneously with those for ^{55}Mn reported in the preceding paper.¹ Our results are shown in Fig. 1. The error bars are statistical only; the systematic errors and photon energy resolution are the same as for the ^{55}Mn measurement.¹

As was the case for ^{55}Mn , the giant resonance of ^{59}Co is very broad, with considerable strength in the region of 24 MeV in addition to the two main peaks near 17 and 19 MeV. The latter both have peak cross sections of about 75 mb, about 10% larger than the peak value found in a previous low-resolution measurement at this laboratory.² Both the total photoneutron cross section and the $(\gamma,2n)$ cross section (which has a peak value of 17 mb at 22 MeV) exhibit considerable fine structure, including a well-defined shoulder just above the (γ,n) threshold.

The integrated total photoneutron cross section, up to 36.5 MeV is 894 MeV mb, while that for the $(\gamma,2n)$ reactions is 139 MeV mb. The $(\gamma,3n)$ cross section, up to 37 MeV, is quite small, as indicated in Fig. 1d.

† Work performed under the auspices of the U. S. Atomic Energy Commission.

1 R. A. Alvarez, B. L. Berman, F. H. Lewis, P. Meyer: preceding paper.

2 S. C. Fultz, R. L. Bramblett, J. T. Caldwell, N. E. Hansen, and C. P. Jupiter, Phys. Rev. 128, 2345 (1962).

(over)

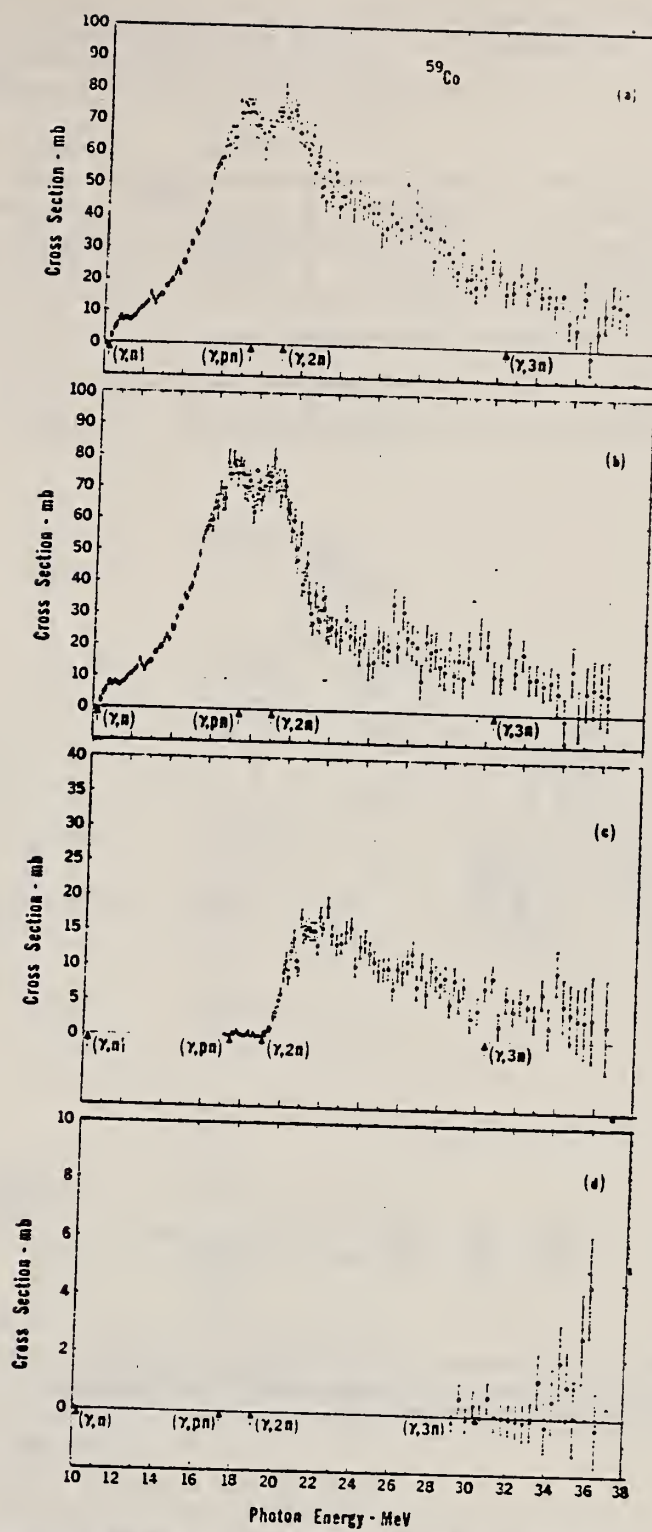


Figure 1. Photoneutron cross sections of ^{59}Co . Thresholds are indicated by arrows.
 (a) Total photoneutron cross section: $\sigma[(\gamma,n) + (\gamma,pn) + (\gamma,2n) + (\gamma,3n)]$;
 (b) $\sigma[(\gamma,n) + (\gamma,pn)]$; (c) $\sigma(\gamma,2n)$; (d) $\sigma(\gamma,3n)$.

METHOD

REF. NO.

73 Ba 20

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	NOX	THR- 27	C	10- 27	BF3-I		4PI

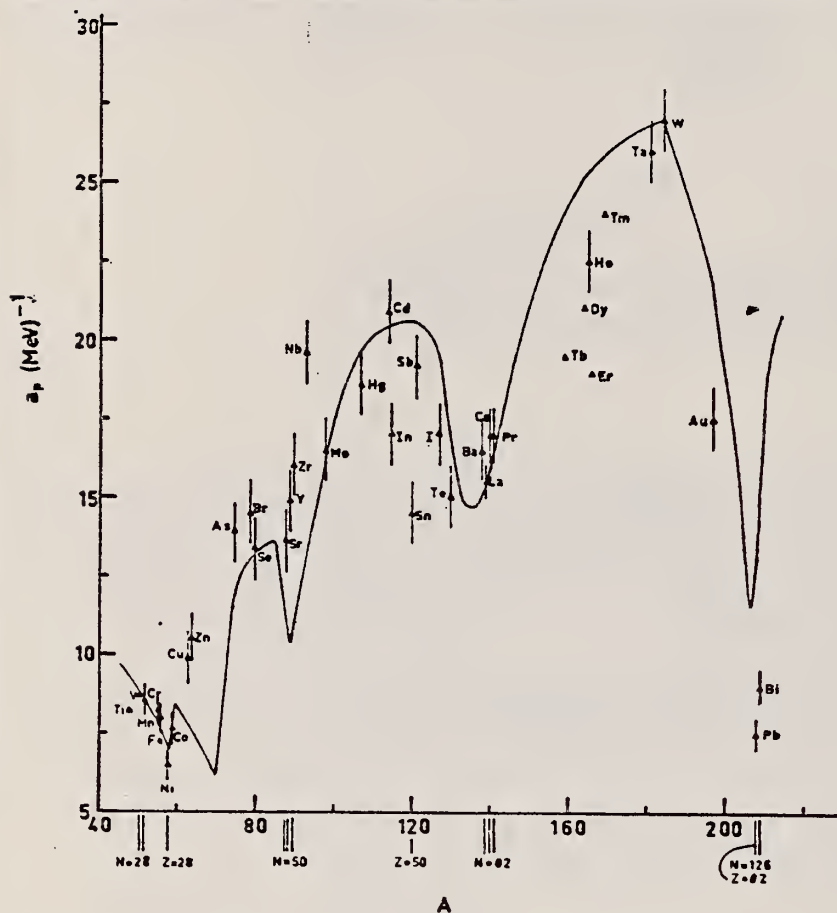


Fig. 12. Experimental values of the level density parameter a_p (Fermi gas formula plus pairing correction) versus atomic number A . The continuous curve is a least-squares fit to the data of a theoretical calculation from Newton ¹³.

- 1 H. Baba and S. Baba, Japan Atomic Energy Research Institute report JAERI-1183 (1969).
- 2 H. Baba, Nucl. Phys. A159, 625 (1970).
- 15 T.D. Newton, Can. J. Phys. 34, 804 (1956).

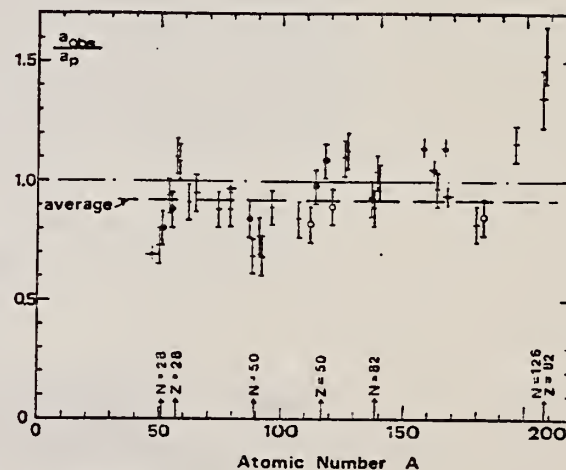


Fig. 15. Ratio a_{obs}/a_p versus atomic number A . Here a_{obs} is the level density parameter taken from the neutron resonance work of refs. ^{1,2}, and a_p is the level density parameter derived from the present (γ, n) work. Filled circles represent points where nuclei in the neutron resonance and in the (γ, n) experiment were the same. Open circles represent points where the respective nuclei were approximately matched. Triangles represent points which are based on measurement of neutron mean energies at two bremsstrahlung energies only.

(over)

TABLE 3

Comparison of experimental and theoretical data on nuclear level densities with Fermi gas formulae, and comparison of nuclear level density parameters from (γ, n) and n-resonance absorption experiments

Target	N (residual nucleus) ^{a)}		Goodness of fit ^{b)}		$\bar{E}_0(24)$ (MeV) ^{c)}	T (MeV) ^{d)}	a_p (MeV ⁻¹) ^{e)}	a_{obs} (MeV ⁻¹) ^{f)}	a_{obs}/a_p
			no	with					
			p.c.	p.c.					
Ti ^{g)}	23	8%			1.93		8.1- ⁴⁷ Ti	6.41- ⁴⁷ Ti	0.79
	24	8%							
	25	73%							
	26	5%							
	27	5%							
V ^{g)}	27	100%			1.96		8.7- ⁵⁰ V	6.35- ⁵¹ V	0.73
Cr	25	4%	P	G	1.89		8.6- ⁵¹ Cr	6.9 - ⁵¹ Cr	<u>0.80</u>
	27	84%							
	28	10%							
	29	2%							
Mn	29	100%	V.P.	G	2.1		8.2- ⁵⁴ Mn	7.82- ⁵⁶ Mn	0.94
Fe	27	6%	F	G	1.96		8.0- ⁵⁵ Fe	7.06- ⁵⁵ Fe	<u>0.88</u>
	29	92%							
	30	2%							
Co	31	100%	P	F	2.12		7.7- ⁵⁸ Co	8.35- ⁶⁰ Co	1.08
Ni (Z = 28)	29	68%	V.P.	P	2.04	1.4	6.5- ^{57.7} Ni	7.19- ⁵⁹ Ni	1.10
	31	26%							
	32	1%							
	33	4%							
	35	1%							
Cu	33	69%	V.P.	P	1.78	1.0	9.8- ⁶² Cu	8.90- ⁶⁴ Cu	0.91
	35	31%							
Zn	33	49%	F	F	1.61		10.5- ^{64.4} Zn	10.0- ⁶⁵ Zn	0.95
	35	28%							
	36	4%							
	37	19%							
As	41	100%	V.P.	F	1.44		14.5- ⁷⁴ As	12.81- ⁷⁶ As	0.88
Se ^{g)}	41	9%			1.39		13.3- ⁷⁸ Se	12.8 - ⁷⁸ Se	<u>0.97</u>
	42	8%							
	43	24%							
	45	50%							
	47	9%							
Br	43	45%	V.P.	V.P.	1.41		14.5- ⁷⁹ Br	12.69- ⁸⁰ Br	0.88
	45	49%							
Sr	47	10%	F	G	1.31		13.6- ⁸⁷ Sr	11.4 - ⁸⁷ Sr	<u>0.84</u>
	48	7%							
	49	83%							

^{a)} Neutron numbers and abundances of respective residual nuclei in (γ, n) experiments.

^{b)} These give an assessment of the goodness of fit of a calculated \bar{E}_n versus E_0 curve to the observed data, using the Fermi gas level density formula both without and with pairing corrections.

^{c)} Bremsstrahlung photoneutron mean energies \bar{E}_n for peak bremsstrahlung energy $E_0 = 24$ MeV.

^{d)} Nuclear temperature from fit with constant-temperature formula.

^{e)} Level density parameter a_p derived from the present (γ, n) experiment, using a Fermi gas formula plus pairing correction, and corresponding residual nucleus (the atomic weight shown is the weighted average of atomic weights of the respective isotopes present).

^{f)} As column 7, but using data on n-resonance absorption from refs. 1, 2).

^{g)} Measurements of $\bar{E}_n(E_0)$ for these nuclei were made only for $E_0 = 21, 23$ and 24 MeV.

REF.

M. Eriksson and G. G. Jonsson
PICNS-73, Vol.II, p.995 (1973) Asilomar

ELEM. SYM.

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Co

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27

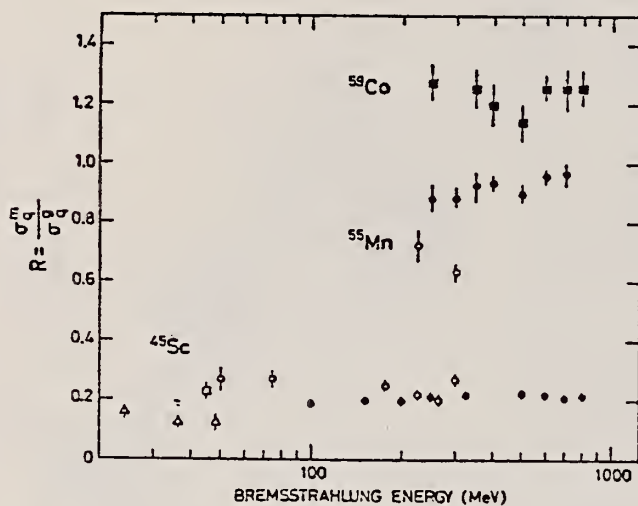
METHOD

REF. NO.

73 Er 1

egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SPL	NOX	0-800	C	100-800	ACT-I		4PI

SC-44 ISOMER RATIO

Isomeric yield ratio,
 $^{44}\text{Sc}^m(6+)/^{44}\text{Sc}^g(2+)$,
 versus bremsstrahlung
 end point energy.

⊗, ⊠ this work, Δ ref 1,
 ○ ref 2, □ ref 3.

- ¹J.R. Tatarczuk and H.A. Medicus, Phys. Rev. 143 (1966) 818.
- ²W.B. Walters and J.P. Hummel, Phys. Rev. 150 (1966) 867.
- ³R. Völpel, Nucl. Phys. A182 (1972) 311.

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		egf
73 Ja 3		

METHOD					
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,NA24	ABY	THR-999	C	100-999	4PI

999=1 GEV

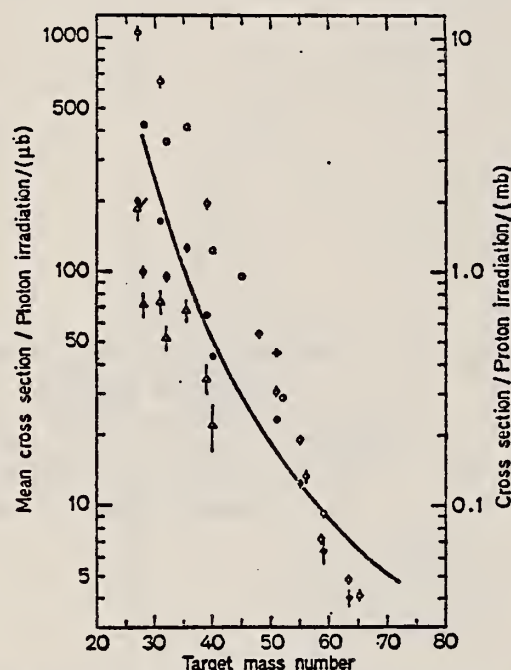


Fig. 7. Mean cross sections for ^{24}Na production as a function of target mass number. Present work filled circles. Noga *et al.* [3] open triangles, Kumbartzki *et al.* [13] cross and Korteling *et al.* [1] 400 MeV protons open circles. The solid line gives the mean cross sections calculated by Jonsson *et al.* [17]

- ¹Korteling, R.G. *et al.*, J. Inorg. Nucl. Chem. 29, 2863 (1967).
- ³Noga, V.I. *et al.*, Sov. J. Nucl. Phys. 9, 637 (1969).
- ¹³Kumbartzki, G. *et al.*, Nucl. Phys. A176, 23 (1971).
- ¹⁷Jonsson, G.G. *et al.*, LUNP7212, Oct. 1972, to be published in Physica Scripta.

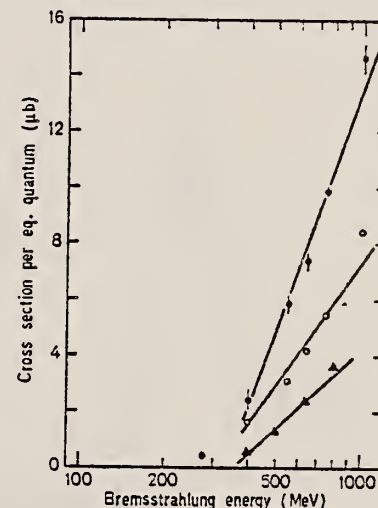


Fig. 6

Fig. 6. The determined yields for the reactions $^{55}\text{Mn} \rightarrow ^{24}\text{Na}$ (filled circles), $^{59}\text{Co} \rightarrow ^{24}\text{Na}$ (open circles) and $^{63,65}\text{Cu} \rightarrow ^{24}\text{Na}$ (filled triangles)

REF.

A.I. Abramov, V.Ya. Kitaev, and M.G. Yutkin
 Izv. Akad. Nauk SSSR. Ser. Fiz. 38, 2112 (1974)
 Bull. Acad. Sci. USSR Phys. Ser. 38, 85 (1974)

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		
74 Ab 12		
METHOD		
hmg		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABX	10- 13	C	11, 13	TOF-D		78
		(10.5-12.5)		(11.5-12.5)			

TABLE 3

Energy Levels of ^{59}Co

E_L^0 , keV	E_c , keV	E , MeV	E_L^0 , keV	E_c , keV	E , MeV	E_L^0 , keV	E_c , keV	E , MeV
2.06	2.02	10.4622	7.83	7.79	10.4680	20.5	20.6	10.4808
2.34	2.29	10.4625	9.3	9.3	10.4695	23.9	24.0	10.4842
2.53	2.53	10.4627	11.6	11.6	10.4718	29.4	29.6	10.4898
2.84	2.79	10.4630	15.1	15.1	10.4753	45.5	45.8	10.5060
3.60	3.55	10.4638	16.2	16.2	10.4764	75.2	75.8	10.5360
4.70	4.65	10.4649						

*On the assumption that all the observed resonances correspond to transitions to the ground state of ^{58}Co , for which $Q_\beta = 10.4602$ MeV [9].

⁹N.B. Gove et al., Nucl. Data Tables, Vol. II, 127 (1972).

TABLE 4

Parameters of the 3.6 keV Resonance of ^{59}Co

E_L^0 , keV	σ_0 , mbarn	Γ , ev	$E_\gamma \Gamma_\gamma$, ev
3.6	54.8 ± 9.6	915 ± 92	1.27 ± 0.23

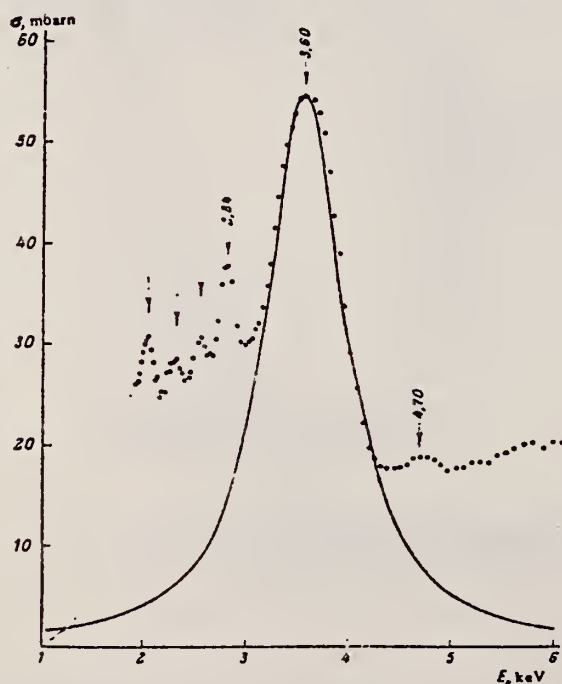


Fig. 5. Differential (γ , n) cross sections for cobalt measured at $E_Y^{\text{max}} = 11.5$ MeV at 78° and multiplied by 4π .

REF.

P. David, J. Debrus, F. Lubke, H. Mommsen, R. Schoenmackers,
and G. Stein
Nucl. Phys. A221, 145 (1974)

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		egf
74 Da 2		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P -	ABY	10-450	C	450	TEL-D		90
G,T	ABY	22-450	C	450	TEL-D		90
G,HE *	ABY	30-450	C	450	TEL-D		90
G,A	ABY	17-450	C	450	TEL-D		90

* HE=HE3

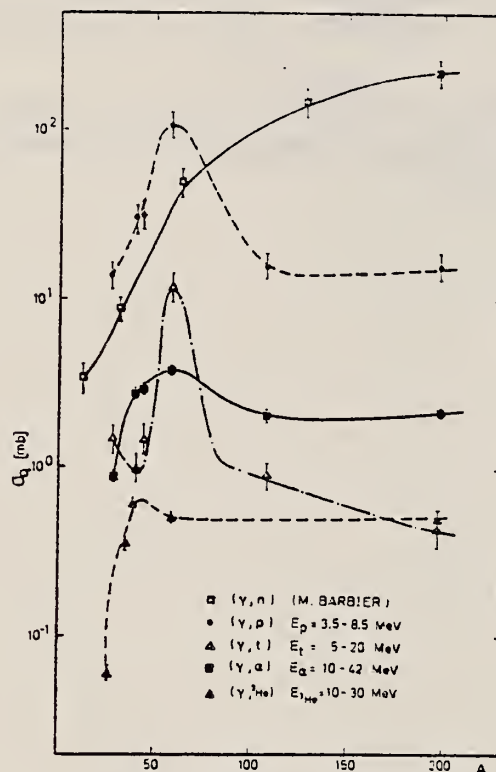


Fig. 5. Yield of protons, tritons, ^3He and ^4He depending on mass number A [ref. 23]. The lines through the points are to guide the eye.

23) M. Barbier, Induced Radioactivity
(North-Holland, Amsterdam, 1969)

(over)

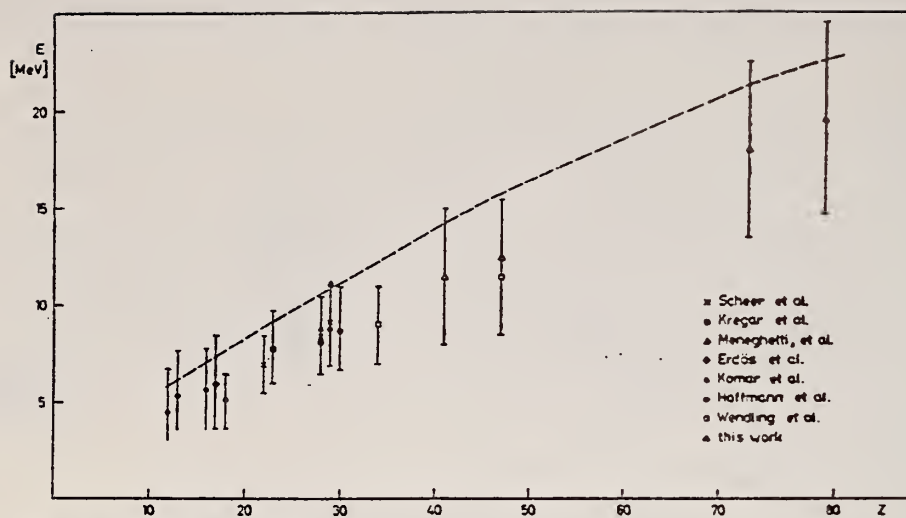


Fig. 8. The position of maxima of the (γ, α) spectra and the width of the spectra at half height. The broken line gives the height of the Coulomb barrier.

REF. M. Boivin, Y. Cauchois, Y. Heno, C. Schloesing-Moller,
V. Zecevic
C.R. Acad. Sc. Paris 281B, 201 (1975)

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		
75 Bo 11		egf

METHOD					
REACTION	RESULT	EXCITATION ENERGY	SOURCE		ANGLE
			TYPE	RANGE	
G,G	LFT	1	C	2	UKN

1190 KEV

TABLEAU

Niveau.... ⁶³Cu 670 ⁶³Cu 771 ⁶³Cu 962 ⁶³Cu 1115 ¹¹⁵In 1133 ⁵⁹Co 1190
τ (ps)..... 0,28 ± 8 % 0,15 ± 12,5 % 0,76 ± 15 % 0,38 ± 14 % 0,094 ± 4,5 % 0,074 ± 3 %

REF. M. Eriksson and G. G. Jonsson Nucl. Phys. <u>A242</u> , 507 (1975)			ELEM. SYM. A Z				
			Co 59 27				
METHOD			REF. NO.				
			75 Er 2				
			egf				
REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,SC44	ABY	THR-800	C	250-800	ACT-I		4PI

ISOMER RATIO

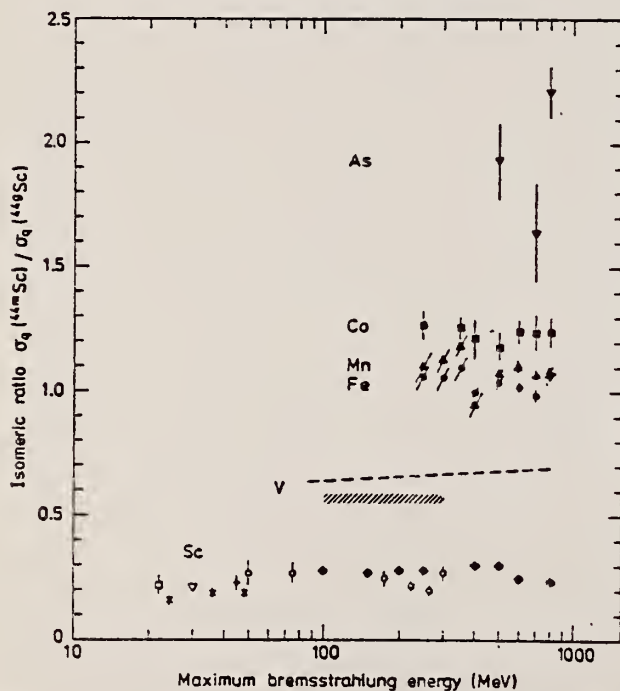


Fig. 6. Isomeric ratio $\sigma_0(^{44m}\text{Sc})/\sigma_0(^{44g}\text{Sc})$ versus bremsstrahlung end-point energy for the different targets. Sc target: \diamond - this work, \square - ref. ¹⁵, \times - ref. ¹⁶, ∇ - ref. ¹⁷, $+$ - ref. ¹⁸, \circ - ref. ¹⁹; V target: dashed curve - ref. ²⁰, dashed area - ref. ²¹; Fe target: \bullet - this work; Mn target: \blacktriangle - this work; Co target: \blacksquare - this work; As target: \blacktriangledown - this work.

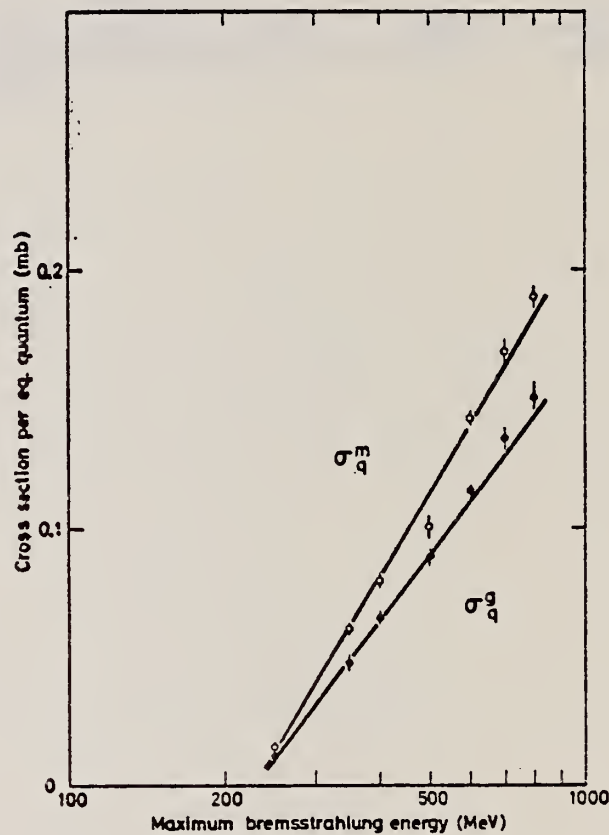


Fig. 5. Yield curves for the reaction $^{59}\text{Co}(\gamma, 6p9n)^{44}\text{Sc}$.

(over)

TABLE 2
Comparison between experimental and calculated cross sections and isomeric ratios

Target	$\bar{\sigma}_{exp}$ (mb) 250-800 MeV	σ_{MC} (mb) 400 MeV	$\bar{\sigma}_{SE}$ (mb) 250-800 MeV	$\sigma(m)/\sigma(g)_{exp}$ 250-800 MeV	$\sigma(m)/\sigma(g)_{calc}$ 400 MeV
⁴³ Sc	≈ 0.5	0.58 ± 0.05		≈ 0	0.05
⁵¹ V	≈ 0.5	0.48 ± 0.05	0.47	0.7	0.72
⁵⁵ Mn	0.40 ± 0.14	0.59 ± 0.05	0.28	1.08 ± 0.04	1.04
Fe	0.40 ± 0.14		0.26	1.00 ± 0.05	
⁵⁹ Co	0.26 ± 0.10	0.34 ± 0.04 $0.65 \pm 0.07^*)$	0.18	1.26 ± 0.06	1.12 1.15 ^{a)}
⁷³ As		0.01 ± 0.01	0.044	1.9 ± 0.3	

^{a)} 325 MeV.

- 15) S. A. Steinberg, B. Sc. thesis, Univ. of Illinois, 1963, unpublished (value taken from ref. 1⁶))
- 16) J. R. Tatarczuk and H. A. Medicus, Phys. Rev. 143 (1966) 818
- 17) T. Kato and Y. Oka, Talanta 19 (1972) 515
- 18) R. Völpe, Nucl. Phys. A182 (1972) 411
- 19) W. B. Walters and J. P. Hummel, Phys. Rev. 150 (1966) 867
- 20) B. Bülow, Lund, private communication (preliminary results)
- 21) R. A. Meyer, thesis, Univ. of Illinois, 1963, unpublished

REF.

C. O. Wene
Z. Phys. A272, 77 (1975)

ELEM. SYM.	A	Z
Co	59	27

METHOD

REF. NO.
75 We 4
egf

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	ABX	18	D	18	SCD-D		90

18 = 17.6 MEV

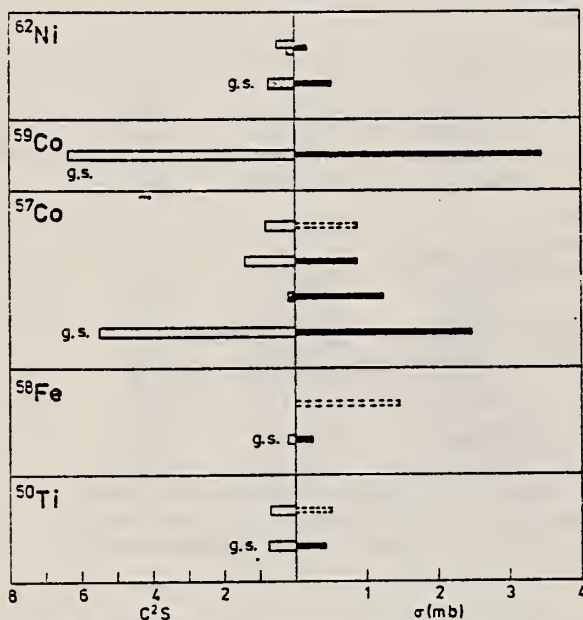


Fig. 5. Correlation between the spectroscopic factors and the cross-sections measured in this work. Open staples indicate $l_p = 3$ pick-up and cross hatched staples $l_p = 1$ pick-up. Dashed staples indicate that the cross section is uncertain due to the subtraction of a large back-ground

Table 2

Daughter nucleus	Level		σ^a (mb)
	(MeV)	J^π	
^{44}Ca	0	0^+	$\leq 0.2^b$
	1.16	2^+	$\leq 0.5^b$
^{50}Ti	0	0^+	0.41 ± 0.05
	2.68	4^+	$(0.5)^c$
^{58}Fe	0	0^+	0.23 ± 0.08
	3.24?	$0^+?$	$(1.5)^c$
^{57}Co	0	$7/2^-$	2.5 ± 0.2^d
	1.76	$3/2^-$	1.2 ± 0.3
	1.90	$7/2^-$	0.9 ± 0.2
	2.31	$7/2^-$	$(0.9)^c$
^{59}Co	0	$7/2^-$	3.5 ± 0.8
^{62}Ni	0	0^+	0.51 ± 0.09
	1.18	2^+	0.2 ± 0.1

^a The quoted errors are only those due to counting statistics.

^b Confidence level 95%.

^c Uncertain because of large background.

^d $\sigma = 2.4$ mb from [43].

43. Miyase, H., Oikawa, S., Suzuki, A., Uegaki, J., Saito, T., Sugawara, M., Shoda, K.: The photoproton reactions of Ni-isotopes. In: Proc. Int. Conf. Photonnuclear Reactions and Applications, Vol. I, p. 553. Livermore, USA 1973 (see Ref. 13)

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$P,G	ABX	12- 23	D	5- 15	NAI-D		DST

POLARIZED PROTONS

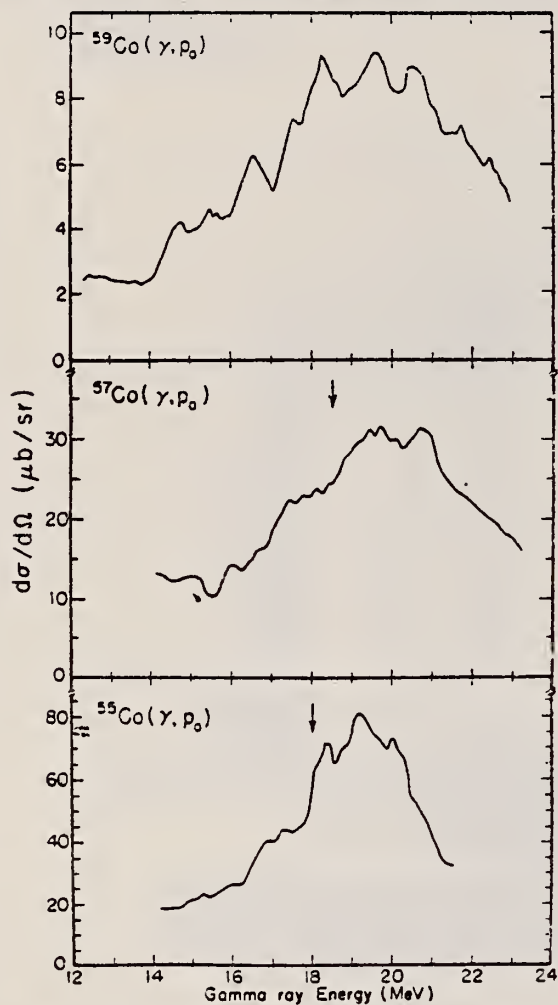


FIG. 3. The 90° yield curves for the $^{54,56,58}\text{Fe}(p, \gamma)$ reactions after averaging over a 500 keV interval. The arrows indicate the energy of the splitting between the T_{\leq} and T_{\geq} components of the GDR as suggested in Ref. 1.

$$\sigma(\theta) = a_0 \left[1 + \sum_i \frac{a_i}{a_0} Q_i P_i(\cos\theta) \right],$$

$$A(\theta) = \left(\frac{N_+ - N_-}{N_+ + N_-} \right) \frac{1}{P}. \quad (\text{Where } N_+ \text{ and } N_- \text{ are counts spin up and counts spin down.})$$

$$A(\theta)\sigma(\theta)/a_0 = \sum_i b_i Q_i P_i^2(\cos\theta).$$

- ¹J.V. Maher, L. Meyer-Schutzmeister, E.L. Sprenkel-Segel, D. von Ehrenstein, R.J. Nemanich, G.C. Kiang, J.F. Tonn, and R.E. Segel, Phys. C9, 1440 (1974).

(over)

TABLE III. The a and b coefficients obtained from least square fits to the data as described in the text. Higher order coefficients are given only when the criterion of normalized χ^2 justified the use of higher order terms.

E_p (MeV)	a_1/a_0	a_2/a_0	a_3/a_0	b_1	b_2	b_3
$^{54}\text{Fe}(\bar{p}, \gamma_0)^{54}\text{Co}$						
8.0	0.26 ± 0.06	0.11 ± 0.11		-0.03 ± 0.05	0.00 ± 0.04	-0.02 ± 0.04
9.0	0.20 ± 0.05	0.09 ± 0.10		-0.07 ± 0.04		
10.0	0.25 ± 0.04	0.03 ± 0.07		0.02 ± 0.03	-0.09 ± 0.02	
11.0	0.10 ± 0.03	0.24 ± 0.05		0.03 ± 0.02	-0.07 ± 0.02	
12.1	0.27 ± 0.05	0.18 ± 0.04	0.18 ± 0.07	0.01 ± 0.01	-0.12 ± 0.01	
13.0	0.01 ± 0.03	-0.09 ± 0.05		0.03 ± 0.02	-0.15 ± 0.01	
14.0	0.07 ± 0.03	0.0 ± 0.05		-0.02 ± 0.02	-0.16 ± 0.02	-0.02 ± 0.02
15.0	0.18 ± 0.03	-0.12 ± 0.06		0.01 ± 0.02	-0.20 ± 0.02	-0.03 ± 0.02
$^{56}\text{Fe}(\bar{p}, \gamma_0)^{57}\text{Co}$						
8.0	0.27 ± 0.06	0.03 ± 0.12		0.08 ± 0.05	-0.01 ± 0.04	
9.0	0.07 ± 0.04	-0.04 ± 0.08		-0.05 ± 0.03	-0.06 ± 0.02	-0.03 ± 0.02
10.0	0.08 ± 0.03	0.24 ± 0.06		0.05 ± 0.02	-0.08 ± 0.02	-0.02 ± 0.02
11.5	0.03 ± 0.03	0.20 ± 0.05		-0.08 ± 0.03	-0.09 ± 0.02	
13.0	0.14 ± 0.03	0.15 ± 0.05		0.02 ± 0.02	-0.22 ± 0.02	-0.03 ± 0.02
14.5	0.14 ± 0.04	-0.34 ± 0.08		0.10 ± 0.03	-0.21 ± 0.02	-0.04 ± 0.02
$^{58}\text{Fe}(\bar{p}, \gamma_0)^{57}\text{Co}$						
7.6	0.19 ± 0.05	0.19 ± 0.09		0.04 ± 0.03	-0.02 ± 0.03	
9.2	0.12 ± 0.04	0.28 ± 0.07		0.01 ± 0.03	-0.11 ± 0.02	
9.6	0.04 ± 0.04	0.26 ± 0.07		0.06 ± 0.02	-0.17 ± 0.02	
10.5	0.12 ± 0.04	0.15 ± 0.06		0.04 ± 0.02	-0.17 ± 0.02	0.04 ± 0.02
11.2	0.16 ± 0.04	0.09 ± 0.06		0.08 ± 0.02	-0.18 ± 0.02	
11.9	0.18 ± 0.05	-0.14 ± 0.09		0.03 ± 0.03	-0.20 ± 0.03	-0.04 ± 0.03
12.7	0.13 ± 0.05	-0.25 ± 0.09		0.07 ± 0.03	-0.23 ± 0.02	
13.5 ^a	0.08 ± 0.09	-0.28 ± 0.09	0.00 ± 0.14	0.06 ± 0.03	-0.22 ± 0.02	
14.0 ^a	0.14 ± 0.09	-0.47 ± 0.08	0.00 ± 0.13	0.08 ± 0.03	-0.20 ± 0.02	-0.04 ± 0.02
15.0 ^a	0.08 ± 0.10	-0.29 ± 0.08	0.00 ± 0.15	0.10 ± 0.03	-0.23 ± 0.02	-0.03 ± 0.02

^a The criterion of normalized χ^2 did not clearly indicate that a fit which included $P_3(\cos \theta)$ was statistically justified for these energies. The error given for a_1 and a_3 reflects this uncertainty.

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		egf
77 Di 6		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,2N	ABY	THR-999	C	300-999	ACT-I		4PI
G,3N	ABY	THR-999	C	300-999	ACT-I		4PI
G,4N	ABY	THR-999	C	300-999	ACT-I		4PI

Abstract—Cross sections per equivalent quantum, in the energy range 0.3–1.0 GeV, have been measured for $^{209}\text{Bi}(\gamma, 2n)$, $^{209}\text{Bi}(\gamma, 3n)$, $^{209}\text{Bi}(\gamma, 4n)$, $^{59}\text{Co}(\gamma, 2n)$, $^{59}\text{Co}(\gamma, 3n)$, $^{59}\text{Co}(\gamma, 4n)$ and $^{51}\text{V}(\gamma, 3n)$ reactions. From the calculated mean absolute cross sections and the data already available in literature for (γ, xn) reactions ($x \geq 1$), a cross section formula has been deduced which reproduces, within a factor of two, most of the experimental cross sections for target nuclei ranging between ^9Be and ^{238}U .

999=1 GeV

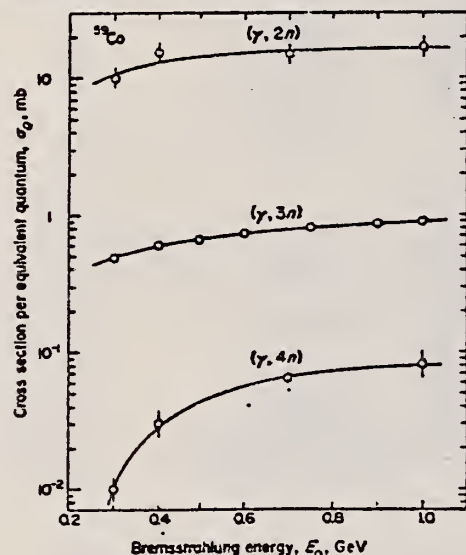


Fig. 2. Yields for the $^{59}\text{Co}(\gamma, xn)$ reactions ($1 \leq x \leq 5$). Smooth curves are drawn "by eye" through the experimental points.

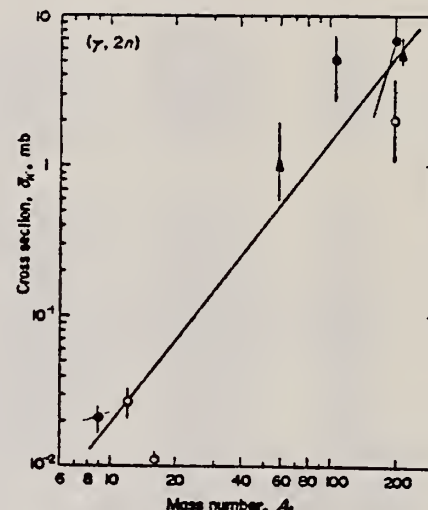


Fig. 4. Experimentally determined mean absolute cross sections, σ_0 , for the $(\gamma, 2n)$ reactions vs the mass number, A , of the target nucleus. Filled circles are taken from our earlier experiments: ^9Be , Ref. [8]; ^{103}Rh , Ref. [4, 6]; ^{197}Au , Ref. [5]. Open circles: ^{12}C and ^{16}O , Ref. [16]; ^{197}Au , Ref. [15]. Filled triangles are the results of the present work for ^{59}Co and ^{209}Bi . The straight line is a least-squares fit of the experimental points.

REFERENCES

- V. di Napoli, F. Salvetti, M. L. Terranova, H. G. de Carvalho, J. B. Martins and O. A. P. Tavares, *Gazz. Chim. Ital.* 105, 317 (1975). This review article reports all existing data in literature on cross-section of (γ, n) reactions in complex nuclei at intermediate energies.
- V. di Napoli, F. Dobici, F. Salvetti and H. G. de Carvalho, *Nuovo Cimento* 48B, 1 (1967).
- V. di Napoli, D. Margadonna, F. Salvetti, H. G. de Carvalho and J. B. Martins, *Lett. Nuovo Cimento* 1, 308 (1969).
- V. di Napoli, A. M. Lacerenza, D. Margadonna, F. Salvetti, H. G. de Carvalho and J. B. Martins, *Lett. Nuovo Cimento* 1, 65 (1971).
- C. Aurisicchio, V. di Napoli, F. Salvetti and M. L. Terranova, *Gazz. Chim. Ital.* 102, 378 (1972).
- H. G. de Carvalho, J. B. Martins, O. A. P. Tavares, V. di Napoli, F. Salvetti, *Proceedings of the International Conference on Photonicuclear Reactions and Applications*, Pacific Grove, Cal., Sect 8C5-1 (1973); V. di Napoli, J. B. Martins, G. Persichelli and M. L. Terranova, *Lett. Nuovo Cimento* 11, 179 (1974).
- V. di Napoli, M. L. Terranova, H. G. de Carvalho and J. B. Martins, *Gazz. Chim. Ital.* 104, 463 (1974).
- G. G. Jonsson and B. Forkman, *Nucl. Phys.* A107, 52 (1968).
- G. G. Jonsson, B. Forkman and K. Lindgren, *Phys. Lett.* 26B, 508 (1968).
- G. Andersson, B. Forkman and B. Friberg, Report LUNP 6901, Lund Institute of Technology, Lund University, p. 4, Sect. 8, 1969 (unpublished).
- G. Andersson and B. Forkman, Annual Report, University of Lund, Lund Institute of Technology, p. 48, (1970) (unpublished).
- G. G. Jonsson and B. Persson, *Nucl. Phys.* A153, 32 (1970).
- J. Sternby, Report LUNP 7011, Lund Institute of Technology, Lund University, September 1970 (unpublished). Also quoted in G. G. Jonsson and K. Lindgren, *Phys. Scr.* 7, 49 (1973).
- K. Lindgren and G. G. Jonsson, *Nucl. Phys.* A166, 643, (1971).
- B. Jonsson, M. Nilsson and K. Lindgren, University of Lund Report LUNFD6/NFFR-3005/1-181, LUTFD 6/(TFKF-3003/1-181), October (1976).
- I. Blomqvist, P. Janeček, G. G. Jonsson, R. Petersson, H. Dinter and K. Tesch, *Z. Physik* A278, 83 (1976).
- B. Bülow, B. Jonsson, M. Nilsson and B. Forkman, *Z. Physik* A278, 89 (1976).

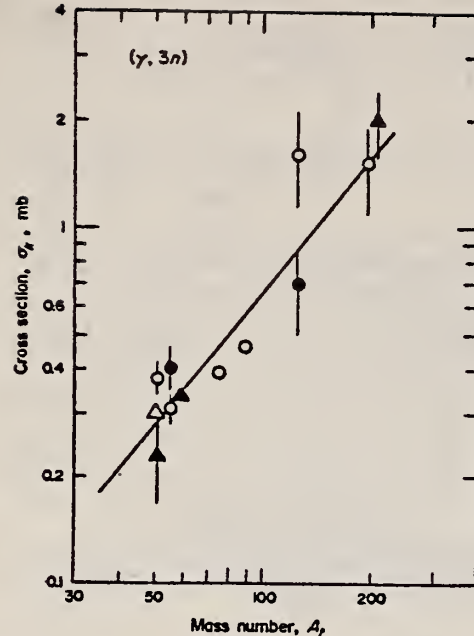


Fig. 5. The same as in Fig. 4 for the $(\gamma, 3n)$ reactions. Filled circles are taken from our earlier experiments: ^{55}Mn , Ref. [7]; ^{127}I , Ref. [3]. Open circles: ^{51}V , Ref. [17]; ^{55}Mn , Ref. [11]; ^{75}As , Ref. [12]; ^{89}Y , Ref. [14]; ^{127}I , Ref. [9, 10, 13]; ^{197}Au , Ref. [15]. Open triangle: ^{51}V , Ref. [18]. Filled triangles are the results of the present work for ^{51}V , ^{59}Co and ^{209}Bi . The straight line is a least-squares fit of the experimental points.

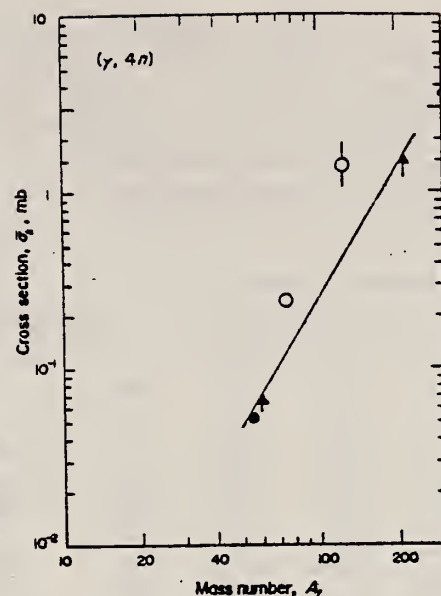


Fig. 6. The same as in Fig. 4 for the $(\gamma, 4n)$ reactions. Filled circle is taken from our earlier experiment: ^{55}Mn , Ref. [7]. Open circles: ^{75}As , Ref. [12]; ^{127}I , Ref. [9, 10, 13]. Filled triangles are the results of the present work for ^{59}Co and ^{209}Bi . The straight line is a least-squares fit of the experimental points.

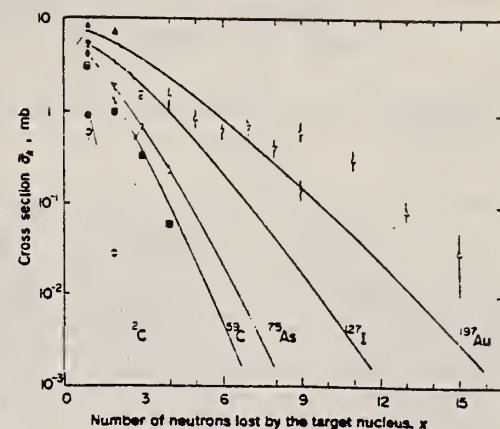


Fig. 7. Cross section distributions for the (γ, xn) reactions ($x \geq 1$) at intermediate energies (0.2–1.0 GeV). Experimental data are taken from: filled circle: ^{12}C Ref. [1]; open circles: ^{12}C , Ref. [1, 16]; filled squares: ^{59}Co , this work and Ref. [1]; open square: ^{59}Co , Ref. [1]; filled rhomb: ^{75}As , Ref. [1]; open rhombs: ^{75}As , Ref. [12]; filled reversed triangles: ^{127}I , Ref. [1, 3]; open reversed triangles: ^{127}I , Ref. [1, 9, 10, 13]; filled triangles: ^{197}Au , Ref. [1, 5]; open triangles: ^{197}Au , Ref. [15]. The full lines represent the calculated cross section distributions according to eqn (12).

Table 2. Mean absolute cross sections for the (γ, xn) reactions, with $1 < x < 5$, in complex nuclei at intermediate energies.

Target nucleus	Reaction	Energy-range (GeV)	Ref.	Cross section, $\bar{\sigma}_x$ (mb)	(Experimental)	(Calc.†)
^9Be	$(\gamma, 2n)$	0.3–1.0	8	0.021 ± 0.002		0.007
^{12}C	$(\gamma, 2n)$	0.2–0.8	16	0.0277 ± 0.0004		0.025
^{16}O	$(\gamma, 2n)$	0.2–0.8	16	0.0113 ± 0.0003		0.072
^{51}V	$(\gamma, 3n)$	0.3–1.0	This work	0.23 ± 0.06		0.268
		0.25–0.60	17	0.38 ± 0.04		0.268
		0.25–0.80	18	0.307 ± 0.012		0.268
^{55}Mn	$(\gamma, 3n)$	0.3–1.0	7	0.41 ± 0.05		0.33
		0.3–0.8	11	0.311 ± 0.016		0.33
	$(\gamma, 4n)$	0.3–1.0	7	0.053 ± 0.004		0.079
^{59}Co	$(\gamma, 2n)$	0.4–1.0	This work	1 ± 1		1.3
	$(\gamma, 3n)$	0.3–1.0	This work	0.337 ± 0.007		0.4
	$(\gamma, 4n)$	0.3–1.0	This work	0.06 ± 0.01		0.1
^{75}As	$(\gamma, 3n)$	0.2–0.9	12	0.39		0.7
	$(\gamma, 4n)$	0.2–0.9	12	0.24		0.24
^{89}Y	$(\gamma, 3n)$	0.25–1.0	14	0.47		1.0
^{103}Rh	$(\gamma, 2n)$	0.4–0.9	4, 6	5.1 ± 2.4		2.7
^{127}I	$(\gamma, 2n)$	0.1–0.8	9	7.4†		3.4
		0.3–1.0	3	20 ± 7		3.4
	$(\gamma, 3n)$	0.3–1.0	3	0.7 ± 0.2		1.9
		0.25–0.9	9, 10, 13	1.6 ± 0.5		1.9
	$(\gamma, 4n)$	0.25–0.9	9, 10, 13	1.4 ± 0.4		1.0
^{197}Au	$(\gamma, 2n)$	0.3–0.9	15	2 ± 2		5.2
		0.3–1.0	5	7 ± 5		5.2
	$(\gamma, 3n)$	0.3–0.9	15	1.5 ± 0.4		3.6
^{209}Bi	$(\gamma, 2n)$	0.3–1.0	This work	6 ± 1		5.5
	$(\gamma, 3n)$	0.3–1.0	This work	2.0 ± 0.4		3.8
	$(\gamma, 4n)$	0.3–1.0	This work	1.3 ± 0.2		2.5

†Calculated values according to eqn (12)

‡Deduced value from the interpolated σ_0 curve as indicated in Ref. [9].

ELEM. SYM.	A	Z
Co	59	27

METHOD	REF. NO.	
	78Di12	hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G, SPL	ABY	THR-999	C	300-999	ACT-I		4PI

Abstract—Cross sections per equivalent quantum, in the energy range 0.3–1.0 GeV, have been measured for spallation residuals from ^{51}V , ^{55}Mn , natural Fe, and ^{59}Co targets. Mean cross sections per photon have been deduced in this energy range and the data analysed in terms of charge-dispersion curves and mass-yield distributions. The mean cross sections per photon have also been compared with a semiempirical Rudstam's formula. A satisfactorily good agreement has been found with the calculated yields within a factor of two.

Table 5. Yields of radionuclides in units of μb per equivalent quantum. Cobalt target

Nuclide	$E_0(\text{GeV})$						
	0.30	0.40	0.50	0.60	0.75	0.90	1.00
^{24}Na		2 ± 1	3 ± 1	5 ± 1	7 ± 1	8 ± 1	8 ± 1
^{25}Mg		3 ± 1	4 ± 1	6 ± 1	8 ± 1	9 ± 1	10 ± 1
^{26}Mg			0.5 ± 0.2	1.0 ± 0.3	1.4 ± 0.3	1.8 ± 0.3	2.0 ± 0.3
^{27}Al	50 ± 3	57 ± 3	64 ± 3	67 ± 3	72 ± 3	77 ± 4	80 ± 4
^{28}Al		5 ± 2	10 ± 3	12 ± 3	16 ± 3	18 ± 3	20 ± 3
^{29}Si		1 ± 1	5 ± 2	10 ± 3	15 ± 3	20 ± 3	20 ± 3
^{30}Si		11 ± 5	20 ± 6	30 ± 6	35 ± 7	45 ± 7	40 ± 7
^{31}P		40 ± 2	42 ± 2	45 ± 2	48 ± 3	50 ± 3	50 ± 3
^{32}S	35 ± 2		2.5 ± 1.0	5.0 ± 1.5	9.6 ± 2.0	11.0 ± 2.0	10.0 ± 2.0
^{36}K	2 ± 1	2 ± 1	10 ± 5	20 ± 5	50 ± 15	70 ± 20	71 ± 20
^{39}K		2 ± 1	5 ± 2	10 ± 3	28 ± 5	30 ± 5	26 ± 5
^{40}K	2.0 ± 1.0	2.0 ± 1.0	5.0 ± 2.0	7.0 ± 3.0	9.0 ± 4.0	11.5 ± 4.0	12.0 ± 4.0
^{41}K	0.8 ± 0.4	1.1 ± 0.5	1.3 ± 0.5	1.5 ± 0.5	1.7 ± 0.5	1.9 ± 0.5	2.0 ± 0.5
^{42}Ca		0.5 ± 0.3	0.5 ± 0.3	1.5 ± 0.8	2.0 ± 0.8	3.0 ± 0.8	2.0 ± 0.8
^{44}Ca	10 ± 4	20 ± 5	40 ± 6	40 ± 6	56 ± 6	65 ± 6	72 ± 6
^{46}Sc	120 ± 10	140 ± 10	150 ± 10	160 ± 10	190 ± 10	210 ± 10	220 ± 10
^{47}Sc	130 ± 13	145 ± 13	160 ± 13	160 ± 13	190 ± 13	210 ± 13	210 ± 13
^{48}Sc	100 ± 30	140 ± 30	200 ± 40	260 ± 40	295 ± 40	335 ± 40	340 ± 40
^{49}Sc	63 ± 20	134 ± 20	130 ± 25	160 ± 30	190 ± 30	214 ± 30	228 ± 30
^{50}Sc	1.0 ± 0.5	7.0 ± 2.0	14.0 ± 3.0	19.0 ± 3.0	23.0 ± 3.0	28.0 ± 3.0	30.0 ± 3.0
^{51}V	300 ± 25	325 ± 25	350 ± 25	370 ± 25	390 ± 25	410 ± 25	420 ± 25
^{52}Cr	10.0 ± 2.5	11.5 ± 2.5	12.6 ± 2.5	13.5 ± 2.5	14.6 ± 2.5	15.6 ± 2.5	16.0 ± 2.5
^{54}Cr	126 ± 8	132 ± 8	136 ± 8	140 ± 8	144 ± 8	148 ± 8	150 ± 8
^{56}Cr	1600 ± 150	1700 ± 150	1800 ± 150	1800 ± 150	1900 ± 150	1960 ± 150	2000 ± 150
^{57}Mn	280 ± 25	320 ± 25	320 ± 25	330 ± 25	340 ± 25	340 ± 25	350 ± 25
^{59}Mn	260 ± 26	260 ± 25	300 ± 25	330 ± 25	300 ± 25	360 ± 25	360 ± 25
^{60}Mn	1200 ± 100	1400 ± 100	1500 ± 100	1600 ± 100	1780 ± 100	1850 ± 100	1900 ± 100
^{64}Fe	14.0 ± 0.8	14.5 ± 0.8	15.0 ± 0.8	15.0 ± 0.8	15.5 ± 0.8	15.8 ± 0.8	16.0 ± 0.8

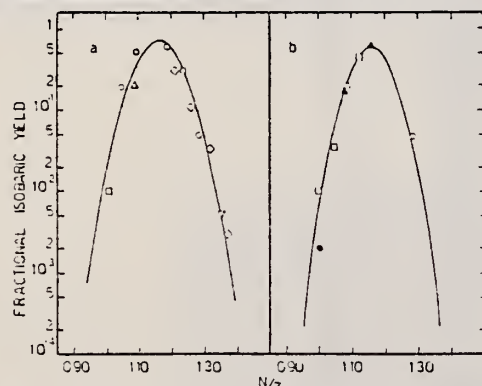


Fig. 3. The same as Fig. 2. ^{59}Co target. Graph (a): $42 \leq A \leq 48$; (b): $48 \leq A \leq 54$. The symbols are the same used in Fig. 2 plus \bullet for Fe isotopes.

Fig. 1. Fractional isobaric yield vs the N/Z ratio for $42 \leq A \leq 48$. Mean cross sections per photon in the energy range 0.3–1 GeV. Graph (a): ^{51}V target; (b): ^{55}Mn target. The symbols are: \square , for Cr; \circ , for Sc; Δ , for V; ∇ , for Ca isotopes.

YLDS 24NA TO 52FE

Table 6. Mean cross sections in the energy range 0.3–1 GeV in units of μb

Produced radio-nuclide	Target nucleus				
	Vanadium		Manganese	Iron	Cobalt
	Present work	Bülow <i>et al.</i> [26]			
^{24}Ne	2.0 ± 0.4				
^{25}Na	16 ± 4				
^{26}Na	30 ± 2	18 ± 2	10 ± 1	10 ± 1	7 ± 1
^{27}Mg	22 ± 2	18 ± 3	9 ± 1	10 ± 1	8 ± 1
^{28}Mg	6 ± 1	6 ± 1	2.7 ± 0.5	2.7 ± 0.5	2.2 ± 0.3
^{29}Al	58 ± 7	59 ± 4	29 ± 4	35 ± 4	25 ± 3
^{30}Al	25 ± 4	32 ± 2	11 ± 2	15 ± 2	16 ± 3
^{31}Si	16 ± 2	14 ± 2	30 ± 4	30 ± 4	19 ± 3
^{32}Cl	75 ± 13	96 ± 5	45 ± 8	50 ± 8	37 ± 7
^{33}Cl	37 ± 7	35 ± 1	12 ± 2	19 ± 3	13 ± 2
^{34}Ar	65 ± 6	54 ± 2	35 ± 4	28 ± 3	12 ± 2
^{36}K	280 ± 50	243 ± 11	94 ± 17	80 ± 15	66 ± 12
^{39}K	128 ± 20	128 ± 4	43 ± 7	30 ± 5	28 ± 5
^{40}K	33 ± 12	30 ± 3	11 ± 4	10 ± 4	9.5 ± 4
^{41}K	12 ± 2	8 ± 1	1.0 ± 0.5	1.2 ± 0.5	1.0 ± 0.5
^{42}Ca	12 ± 4	15 ± 1	6.5 ± 2.4	6 ± 2	2.2 ± 0.8
^{44}Sc	104 ± 10	109 ± 6	72 ± 7	77 ± 8	52 ± 6
^{46}Sc	260 ± 30	243 ± 14	115 ± 15	100 ± 12	84 ± 10
^{47}Sc	230 ± 40	218 ± 13	116 ± 20	90 ± 16	71 ± 13
^{48}Sc	575 ± 100	605 ± 18	260 ± 45	214 ± 35	220 ± 40
^{49}Sc	457 ± 100	540 ± 33	200 ± 45	160 ± 30	127 ± 30
^{50}Sc	165 ± 15	138 ± 8	50 ± 5	30 ± 3	25 ± 3
^{51}V	210 ± 50	307 ± 12	200 ± 50	184 ± 45	100 ± 25
^{52}Cr	20 ± 10	7 ± 3	8 ± 4	5.0 ± 2.5	
^{54}Cr	13 ± 5	16 ± 2	40 ± 15	64 ± 25	20 ± 8
^{56}Cr			480 ± 150	570 ± 150	330 ± 150
^{57}Mn				25 ± 5	
^{59}Mn				75 ± 40	49 ± 25
^{60}Mn				96 ± 40	84 ± 25
^{64}Fe				944 ± 300	584 ± 100
					1.6 ± 0.8

Table 7. N/Z dispersion parameters of the mean cross sections per photon†

Target nucleus	Mass region	A_m	N/Z_p	Z_p	FWHM	ΔZ	Ref.
^{51}V	42–48	45	1.16	20.8	0.143	1.36	Present work
			1.16	20.8	0.142	1.37	[26]
			1.16	20.9	0.168	1.63	[35]
^{55}Mn	42–48	45	1.16	20.8	0.142	1.37	Present work
nat Fe	42–48	45	1.16	20.8	0.140	1.35	Present work
	48–54	51	1.16	23.6	0.126	1.38	Present work
^{59}Co	42–48	45	1.16	20.8	0.141	1.36	Present work
	48–54	51	1.16	23.6	0.124	1.36	Present work

† A_m is the median mass of the mass region under consideration. N/Z_p is the neutron/proton ratio for the most probable nuclear charge Z_p of A_m . FWHM is the full width at half-maximum of the CD curves. ΔZ is the spread in Z as calculated from the FWHM for the two abscissas N/Z_1 and N/Z_2 (see also Refs. [26] and [35]).

REF. D.J.S. Findlay, D.J. Gibson, R.O. Owens, J.L. Matthews
Phys. Lett. 79B, 356 (1978)

ELEM. SYM.	A	Z
Co	59	27

METHOD

REF. NO.
78 Fi 7

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,P	NOX	45-85	C	60-100	MAG-D		DST

Experimental data on the (γ, p) reaction at $E_\gamma = 60-100$ MeV for targets in the range $A = 7-93$ are compared with predictions based on a single-particle knock-out mechanism using shell model wavefunctions. The results show that this mechanism is more important than has generally been believed

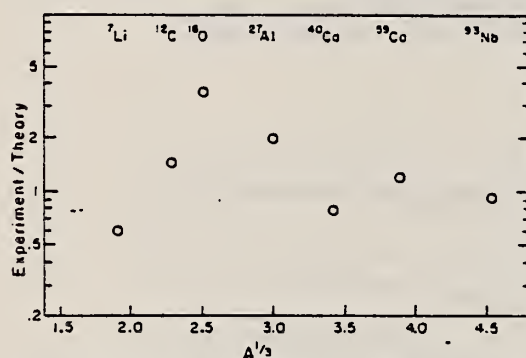


Fig. 2. The ratio of the measured photoproton emission populating low-lying states to the single-particle direct knock-out predictions is shown as a function of nuclear mass A for 80 MeV bremsstrahlung. Errors in the ratio, due to uncertainties in our calculations, are estimated to be a factor of ≈ 1.5 . Errors in the experimental data are negligible.

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		hg
78 Ma 10		

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,N	ABY	10-68	C	30-68	ACT-I		4PI
G,2N	ABY	19-68	C	30-68	ACT-I		4PI

Analysis is made of reactions interfering with photon activation analysis procedures.

The activation yield curves have been presented for a number of photonuclear reactions in the energy range from 30 to 68 MeV, in order to evaluate quantitatively the interferences due to competing reactions in multielement photon activation analysis. The general features of the yields as functions of both target mass number and excitation energy were elucidated from the data obtained, discussion being given on the results in terms of the reaction mechanism.

Simultaneous neutron activation due to appreciable neutron production from the converter and surrounding materials has also been studied, and, finally, the magnitudes of interferences in real multielement analysis were given in the form of their energy dependences.

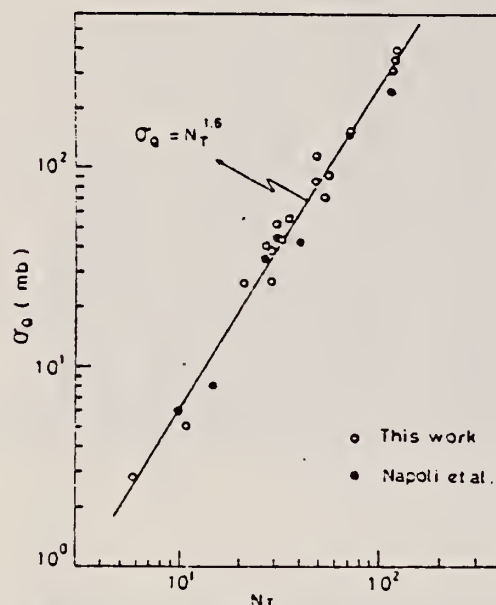


Fig. 2. Yield per equivalent quanta versus target neutron number.

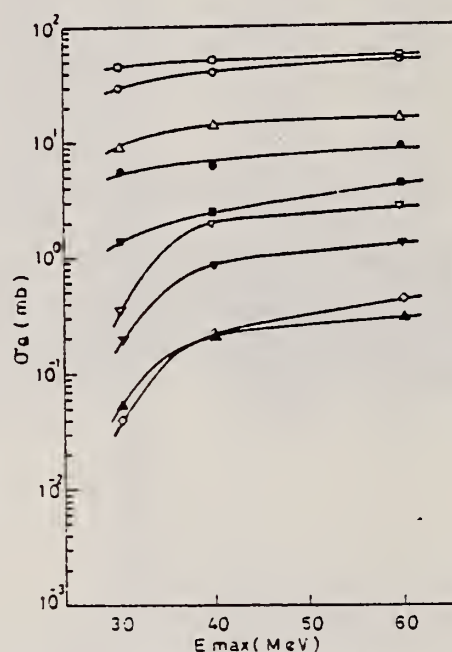


Fig. 6. Activation yield curves for the reactions on Co, Ni and Cu.

○ $^{59}\text{Co}(\gamma, n)^{58}\text{Co}$, ● $^{59}\text{Co}(\gamma, 2n)^{57}\text{Co}$, △ $^{58}\text{Ni}(\gamma, n)^{57}\text{Ni}$,
 7 $^{58}\text{Ni}(\gamma, pn)^{56}\text{Co}$, ▼ $^{60}\text{Ni}(\gamma, pn)^{58}\text{Co}$, ▲ $^{59}\text{Ni}(\gamma, 2n)^{56}\text{Ni}$,
 □ $^{63}\text{Cu}(\gamma, n)^{62}\text{Cu}$, ■ $^{63}\text{Cu}(\gamma, 2n)^{61}\text{Cu}$, ◇ $^{63}\text{Cu}(\gamma, xn)^{53}\text{Co}$.

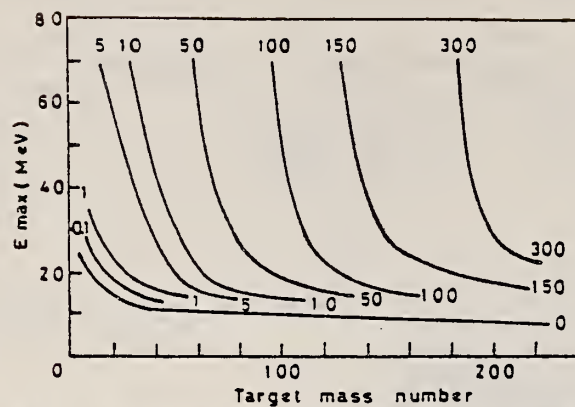


Fig. 9. Yields of the (γ, n) reactions as a function of bremsstrahlung maximum energy and target mass number. The numerical values in the figure are yields per equivalent quanta in mb.

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		
78 Ts 1		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
E,XP	ABX	15- 29	D	15- 29	MAG-D		90

Abstract: The differential cross sections of the (e, e'p) reactions for ^{51}V and ^{59}Co have been measured at 90° over the region of excitation corresponding to the electric giant dipole resonance. The (γ , p) cross sections of these nuclei were deduced from differential cross sections assuming isotropic angular distributions of protons. The results are compared with the (γ , n) cross sections, and are used to obtain strengths of the T_1 and T_2 giant dipole states separately by using the statistical theory. For each nucleus the ratio of the separated strengths and the splitting energy are consistent with those expected by the isospin formalism.

G,XP E1-VIRTUAL PHOT

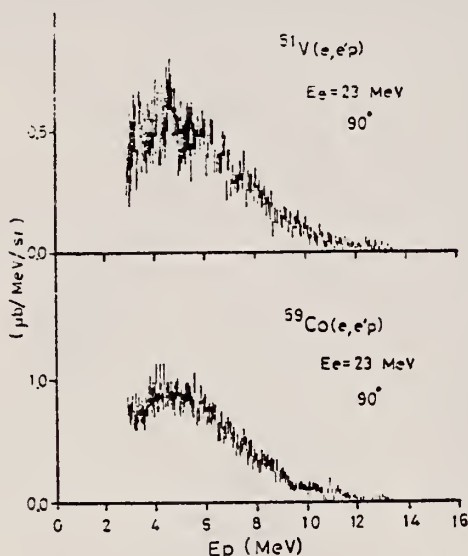


Fig. 2. Typical proton energy spectra of the (e, e'p) reactions of ^{51}V and ^{59}Co nuclei at 23.0 MeV of the incident electron energy.

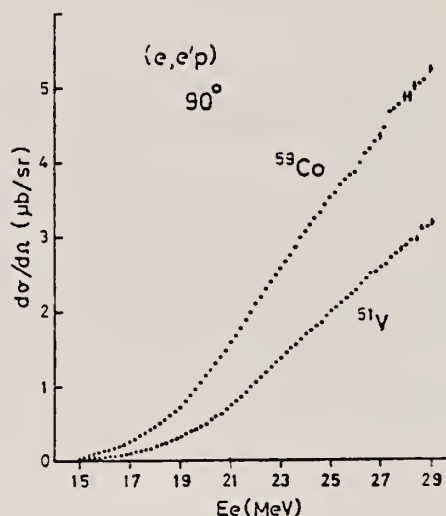


Fig. 3. Proton yield curves of the (e, e'p) reactions of ^{51}V and ^{59}Co nuclei at 90° .

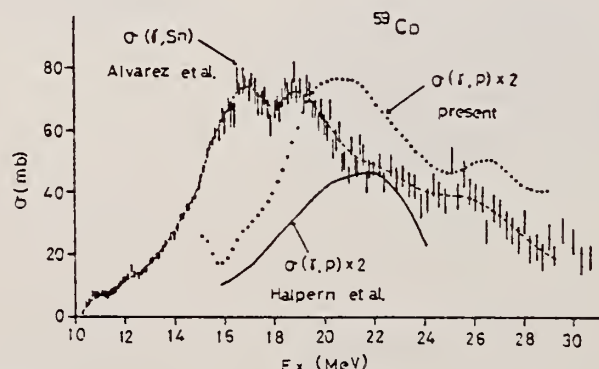


Fig. 6. Comparison between (γ , p) and (γ , Sn) cross sections of ^{59}Co (see the caption to fig. 5).

over

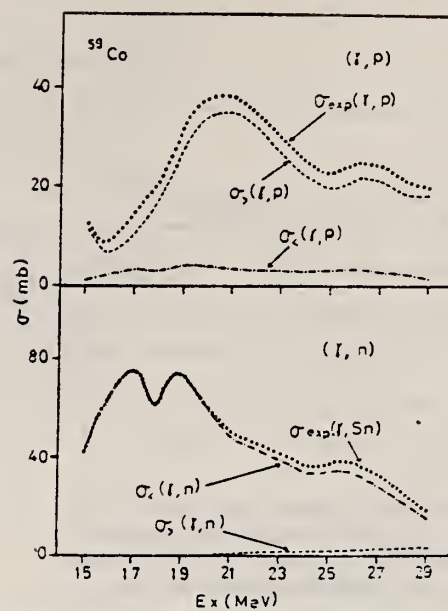


Fig. 9. Comparison between experimental cross sections and separated isospin components of ^{59}Co . Notations are explained in the text.

TABLE 2

Summary of the parameters obtained from the differential cross sections at 90° for ^{51}V and ^{59}Co

	Range of measurement (MeV)	$\int \frac{d\sigma(\gamma, p)}{d\Omega} dE$ (MeV · mb/sr)	$4\pi \int \frac{d\sigma(\gamma, p)}{d\Omega} dE$ (MeV · mb)
^{51}V	15.0-29.0	16.32 ± 1.39	205 ± 17
^{59}Co	15.0-29.0	28.10 ± 2.00	353 ± 25

ELEM. SYM.	A	Z
Co	59	27

METHOD	REF. NO.	
	78 We 4	hmg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
\$ P,G	RLX	14-23	D	7-15	UKN-D		DST

Analysis of data in reference 3.

POLARIZED PROTONS

Measurements of cross sections and analyzing powers are examined for polarized proton capture on ^{14}C , ^{30}Si , ^{54}Fe , ^{56}Fe , ^{58}Fe , ^{59}Co , and ^{88}Sr at energies which cover the giant dipole resonance region. These data are used to extract the relative amplitudes and phases of the contributing $E1$ T -matrix elements. A typical result exhibits two solutions. Calculations using the direct (or a direct-semidirect) capture model appear to provide a means for choosing the physical solution.

NUCLEAR REACTIONS: $^{14}\text{C}(\bar{p}, \gamma_0)$, $^{30}\text{Si}(\bar{p}, \gamma_0)$, $^{54}\text{Fe}(\bar{p}, \gamma_0)$, $^{56}\text{Fe}(\bar{p}, \gamma_0)$, $^{58}\text{Fe}(\bar{p}, \gamma_0)$, $^{59}\text{Co}(\bar{p}, \gamma_0)$, $^{88}\text{Sr}(\bar{p}, \gamma_0)$; measured $\sigma(\theta)$ and $A(\theta)$ over energy region of the giant dipole resonance. Deduced T -matrix amplitudes and phases. Compare results to direct-semidirect model calculations.

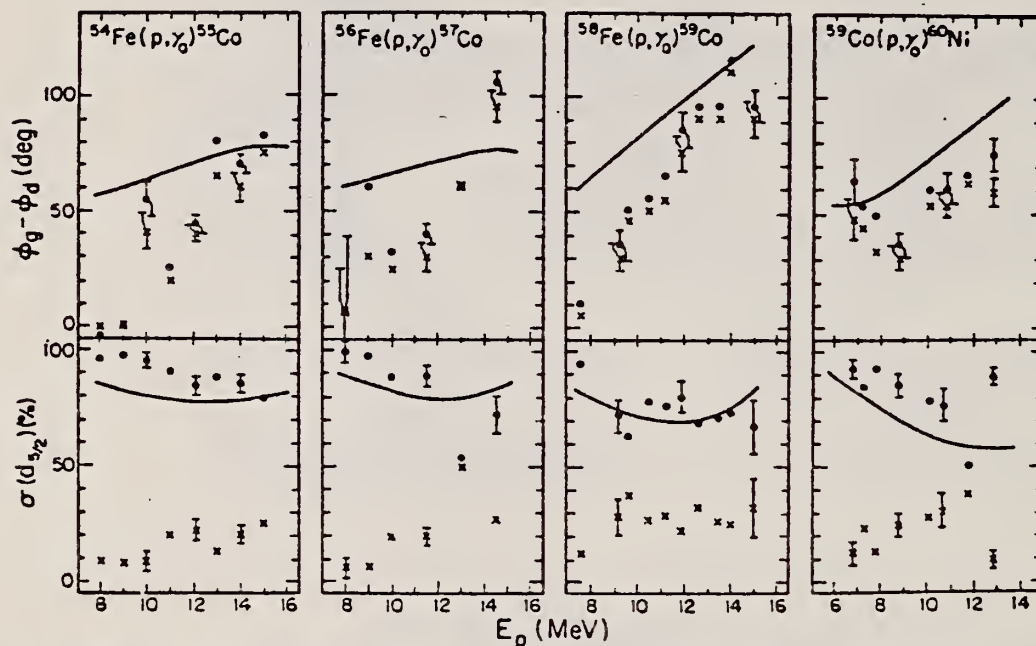


FIG. 2. Same as Fig. 1 for the target nuclei of ^{54}Fe , ^{56}Fe , ^{58}Fe , and ^{59}Co . The remaining cross section is due to the $s_{1/2}$ matrix element.

FIG. 1. The two solutions (dots and x's) resulting from a pure $E1$ analysis of the data are shown along with the results of the calculation for target nuclei of ^{14}C , ^{88}Sr , and ^{30}Si . The remaining cross section in the case of ^{14}C and ^{88}Sr is due to the $s_{1/2}$ matrix element. In the case of ^{30}Si it arises from the $p_{7/2}$ matrix element. The error bars represent typical statistical errors associated with the data points. The amplitudes are presented in terms of the percentage of the total cross section for which they are responsible. The curves represent DSD calculations as described in the text. The dashed curves in the case of ^{88}Sr were obtained using the optical model parameters of Ref. 16 while the solid lines were obtained from the parameters of Ref. 18.

(over)

- ²H. R. Weller, R. A. Blue, N. R. Roberson, D. G. Rickel, S. Maripuu, C. P. Cameron, R. D. Ledford, and D. R. Tilley, Phys. Rev. C 13, 922 (1976). (Note: an error exists in the sign of the phase in this paper. The quantity $\phi_3 - \phi_4$ should be $\phi_4 - \phi_3$ wherever it appears.)
- ³C. P. Cameron, N. R. Roberson, D. G. Rickel, R. D. Ledford, H. R. Weller, R. A. Blue, and D. R. Tilley, Phys. Rev. C 14, 553 (1976).
- ⁴C. P. Cameron, Ph.D. thesis, Duke University, 1976 (unpublished).
- ⁵R. D. Ledford, Ph.D. thesis, Duke University, 1976 (unpublished).
- ⁶J. D. Turner, C. P. Cameron, N. R. Roberson, H. R. Weller, and D. R. Tilley, Phys. Rev. C 17, 1853 (1978).

ELEM. SYM.	A	Z
Co	59	27
METHOD		REF. NO.
		79 A1 2
		hg

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,1N	ABX	10-37	D	10-37	BF3-I		4PI
G,2N	ABX	19-37	D	17-37	BF3-I		4PI
G,3N	ABX	30-37	D	29-37	BF3-I		4PI

Data fits given use Lorentz Lines,
Kerman & Quang, & Dynamic Collective
Models

Photoneutron cross sections, including $\sigma[(\gamma, n) + (\gamma, pn)]$, $\sigma(\gamma, 2n)$, and $\sigma(\gamma, 3n)$, were measured for ^{55}Mn and ^{59}Co from threshold to 36.5 MeV, with a photon energy resolution which varied from 80 keV at the lowest to 170 keV at the highest energies measured. The source of radiation was the monoenergetic photon beam obtained from the annihilation in flight of fast positrons. The partial photoneutron cross sections were determined by neutron multiplicity counting, and the average neutron energies for $(\gamma, 1n)$ and $(\gamma, 2n)$ events were determined simultaneously with the cross-section data by the ring-ratio technique. The cross sections exhibit considerable but weak structure. Other nuclear information extracted from the data includes parameters of the giant dipole resonance, integrated cross sections and their moments, and nuclear symmetry energies. A comparison is made with previous experimental data for these nuclei as well as with theoretical predictions based upon hydrodynamic, vibrational, and dynamic collective models. None of these models fits the data for these odd-even nuclei satisfactorily; more theoretical work is needed for this nuclear mass region.

NUCLEAR REACTIONS ^{55}Mn , $^{59}\text{Co}(\gamma, n, 2n, 3n)$, $E_\gamma = 10 - 36.5$ MeV; measured 4π neutron yield, multiplicities, average energies for monoenergetic photons; $\sigma(E_\gamma, 1n)$, $\sigma(E_\gamma, 2n)$, $\sigma(E_\gamma, 3n)$, GDR parameters, integrated cross sections and moments, nuclear symmetry energies.

TABLE II. Parameters of two-component Lorentz-curve fits to the GDR. The fitting interval used is 14 to 21 MeV.

Nucleus	$E_m(1)$ (MeV)	$\sigma_m(1)^a$ (mb)	$\Gamma(1)$ (MeV)	$E_m(2)$ (MeV)	$\sigma_m(2)^a$ (mb)	$\Gamma(2)$ (MeV)	χ^2
^{55}Mn	16.82 ± 0.10	51.4 ± 4.1	4.33 ± 0.63	20.09 ± 0.12	45.2 ± 2.6	4.09 ± 1.07	1.14
^{59}Co	16.43 ± 0.08	28.3 ± 5.4	2.73 ± 1.08	18.66 ± 0.25	58.4 ± 4.4	7.38 ± 0.79	1.11

^aUncertainties for σ_m given here are relative. The absolute uncertainties are 7%.

TABLE III. Integrated cross sections. $\sigma_{\text{int}}(\gamma, x) = \int \sigma(\gamma, x) dE_\gamma$, integrated from threshold to $E_{\gamma\text{max}}$.

Nucleus	$E_{\gamma\text{max}}$ (MeV)	$\sigma_{\text{int}}(\gamma, 1n)$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, 2n)$ (MeV-mb)	$\sigma_{\text{int}}(\gamma, 3n)$ (MeV-mb)	$\frac{\sigma_{\text{int}}(\gamma, 2n)}{\sigma_{\text{int}}(\gamma, n_t)}$	$\frac{\sigma_{\text{int}}(\gamma, n_t)}{60NZ/A}$	$\frac{\frac{1}{2}\pi[\sigma_m(1)\Gamma(1) + \sigma_m(2)\Gamma(2)]}{60NZ/A}$
^{55}Mn	36.5	567	163	3	0.222	0.90	0.78
^{59}Co	36.5	653	150	4	0.186	0.92	0.91

TABLE IV. Integrated cross-section moments. $\sigma_{-1} = \int \sigma(\gamma, n_t) E_\gamma^{-1} dE_\gamma$ and $\sigma_{-2} = \int \sigma(\gamma, n_t) E_\gamma^{-2} dE_\gamma$, integrated from threshold to $E_{\gamma\text{max}}$.

Nucleus	σ_{-1} (mb)	$\sigma_{-1} A^{-4/3}$ (mb)	σ_{-2} (mb-MeV ⁻¹)	$\frac{\sigma_{-2}}{0.00225A^{5/3}}$	$\frac{\sigma_{-2}K}{0.05175A^{5/3}}$	σ_{-2} (MeV)
^{55}Mn	36.4	0.174	1.93	1.08	0.91 ^a	21.3
^{59}Co	40.1	0.174	2.14	1.06	0.90 ^a	21.7

^aThe values used for the nuclear symmetry energy K are from Table VI.

(over)

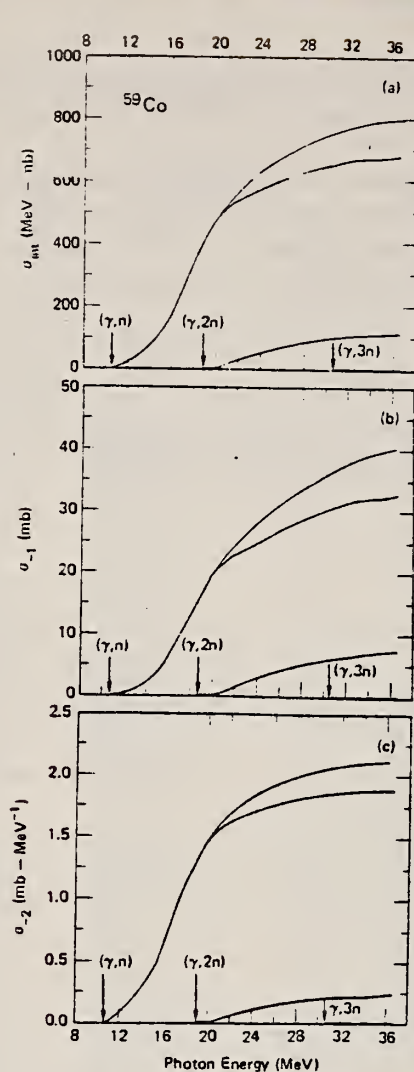


FIG. 5. Running sums of integrated cross sections for ^{59}Co : (a) σ_{int} ; (b) σ_1 ; (c) σ_2 .

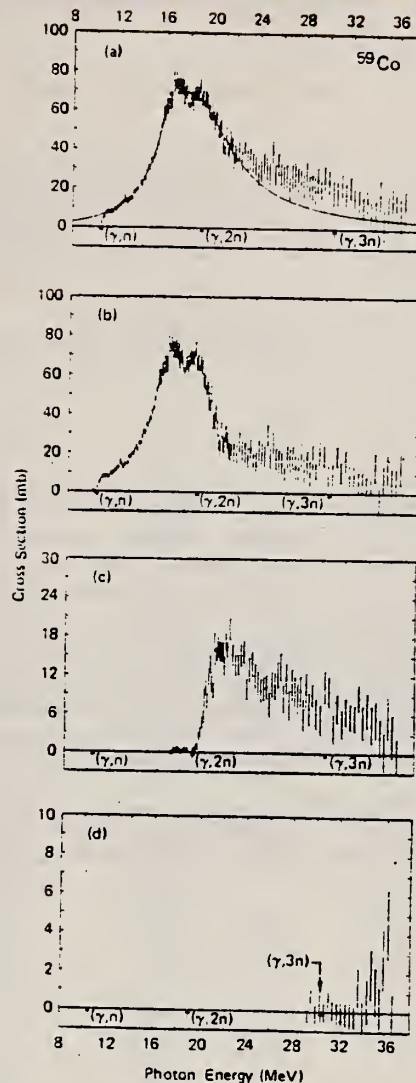


FIG. 3. Photoneutron cross sections for ^{59}Co : (a) $\sigma(\gamma, n_t)$, with a two-component Lorentz-curve fit; (b) $\sigma(\gamma, 1n)$; (c) $\sigma(\gamma, 2n)$; (d) $\sigma(\gamma, 3n)$.

Error bars show statistical uncertainties only.

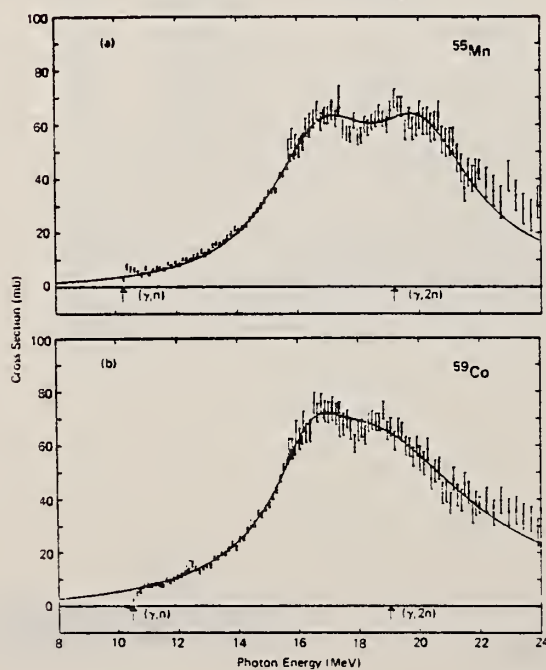


FIG. 6. Total photoneutron cross sections, with two-component Lorentz-curve fits: (a) for ^{55}Mn ; (b) for ^{59}Co . Although the theoretical model is strictly valid only for $\sigma(\gamma, \text{tot})$, the curve shown here was scaled to fit the measured $\sigma(\gamma, n_t)$ data (see Sec. III B in the text and Table III).

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		
81 Ca 2		hg

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
G,G	LFT	1 - 2	C	0 - 2	SCD-D		
		(1.099 - 1.481)					

1.10, 1.46, 1.48 MEV

Abstract. Lifetimes of 49 excited states below 1.65 MeV have been measured in ^{24}Mg , ^{27}Al , ^{48}Ti , ^{58}Ni , ^{59}Co , $^{61,62}\text{Ni}$, $^{63,65}\text{Cu}$, $^{64,66,68}\text{Zn}$, ^{75}As , ^{103}Rh , $^{113,115}\text{In}$, $^{116,118,120}\text{Sn}$ and $^{121,123}\text{Sb}$ by means of nuclear resonance fluorescence experiments. The levels are excited by bremsstrahlung x-ray photons. The self-absorption technique applied to suitable cases provides nuclear absorption cross sections, widths and lifetimes from which the x-ray spectral distributions are also obtained. Scattering experiments are performed for all other cases in order to obtain widths and lifetimes from these x-ray photon curves. The Compton effect in the sample is taken into account. Self-absorption provides $g\Gamma_0$ from which Γ is deduced using adopted J^π and Γ_0/Γ values; scattering provides $u = g(\Gamma_0^2/\Gamma)W(\theta)$ from which Γ is also deduced with J , Γ_0/Γ and mixing ratios taken from the literature. Thanks to simultaneous determination of the x-ray spectra all the lifetimes as given by our programs with their statistical errors form an unusually coherent set of values.

NUCLEAR REACTIONS (γ, γ), bremsstrahlung excitation; natural isotopes; ^{24}Mg , ^{27}Al , ^{48}Ti , ^{58}Ni , ^{59}Co , $^{61,62}\text{Ni}$, $^{63,65}\text{Cu}$, $^{64,66,68}\text{Zn}$, ^{75}As , ^{103}Rh , $^{113,115}\text{In}$, $^{116,118,120}\text{Sn}$ and $^{121,123}\text{Sb}$; $E \approx 0.5\text{--}1.65$ MeV; measured $g\Gamma_0$ or $g(\Gamma_0^2/\Gamma)W(\theta)$; deduced $T_{1/2}$.

(OVER)

Tableau 3. Résultats des mesures des niveaux étudiés par diffusion.

Table 3. Results obtained using the diffusion method.

Isotope	Energie (keV)	J^π	J_0^π	Γ_0/Γ	δ	$u = g(\Gamma_0^2/\Gamma)W(\theta)$ (meV)	τ (ps) ce travail	τ_{ref} (ps)	Références†
²⁴ Mg	1368,59(4)	2 ⁺	0 ⁺	1	E2	1,08(13)	1,76(21)	1,98(4)	Endt et van der Leun (1978)
²⁷ Al	1014,45(3)	$\frac{1}{2}^+$	$\frac{1}{2}^+$	0,971	+ 0,351(12)	0,186(13)	2,20(16)	2,12(8)	Endt et van der Leun (1978)
⁴⁸ Ti	983,512(3)	2 ⁺	0 ⁺	1	E2	0,282(23)	6,74(55)	6,1(13)	Been (1978)
⁵⁸ Ni	1454,45(15)	2 ⁺	0 ⁺	1	E2	2,11(26)	0,90(11)	0,92(3)	Kocher et Auble (1976)
⁵⁹ Co	1099,224(25)	$\frac{3}{2}^-$	$\frac{3}{2}^-$	1	(E2)	0,069(8)	4,79(55)	3,17(58)	Kim (1976)
⁵⁹ Co	1458,8(3)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,91	(E2)	0,68(8)	1,17(14)	1,52(16)	Kim (1976)
⁵⁹ Co	1480,9(3)	$\frac{3}{2}^-$	$\frac{3}{2}^-$	0,8	< 0,35 ^a	1,23(15)	0,254(31)	0,31(3)	Kim (1976)
⁶¹ Ni	1185,7(6)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,77(8) ⁱ	|0,14|	1,88(49)	0,21(5)	0,16(3)	Andreev et al (1974)
⁶² Ni	1172,91(9)	2 ⁺	0 ⁺	1	E2	0,88(17)	2,15(42)	2,09(3)	Halbert (1979a)
⁶³ Cu	1327,00(7)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,84	(E2)	1,04(14)	0,84(11)	0,88(4)	Auble (1979b)
⁶³ Cu	1412,05(4)	$\frac{3}{2}^-$	$\frac{3}{2}^-$	0,72	+ 0,61 ⁽⁺⁹⁾ ₍₋₈₎	0,260(38)	1,90(28)	1,61(3)	Auble (1979b)
⁶⁴ Zn	991,54(7)	2 ⁺	0 ⁺	1	E2	0,640(54)	2,97(25)	2,60(13)	Halbert (1979b)
⁶⁵ Cu	1481,83(5)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,85	(E2)	1,13(19)	0,79(13)	0,49(5)	Auble (1975a)
⁶⁶ Zn	1039,37(6)	2 ⁺	0 ⁺	1	E2	0,70(6)	2,71(23)	2,25(15)	Auble (1975b)
⁶⁸ Zn	1077,38(5)	2 ⁺	0 ⁺	1	E2	0,70(6)	2,71(23)	2,34(23)	Lewis (1975)
⁷⁵ As	572,5(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	1 ^d	0,39 ^b	0,236(26)	4,14(46)	3,5(9)	Horen et Lewis (1975)
⁷⁵ As	823,0(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,86 ^d	(E2)	0,214(22)	4,27(43)	3,5(3)	Robinson et al (1967)
⁷⁵ As	865,5(10)	$\frac{3}{2}^-$	$\frac{3}{2}^-$	0,83 ^d	— ^c	1,78(6)	0,863(68)	0,60(12)	Celliers et al (1977)
⁷⁵ As	1076,0(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,94 ^d	0,38 ^d	0,287(13)	0,287(19)	0,32(7)	Celliers et al (1977)
⁷⁵ As	1128,5(10)	$\frac{1}{2}^+$	$\frac{1}{2}^+$	1	E1 ^d	0,224(24)	1,47(16)	—	
⁷⁵ As	1349,0(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,67 ^d	0,20 ^d	1,61(29)	0,180(32)	0,12(3)	Wilson (1970)
⁷⁵ As	1370,0(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,47 ^d	0,47 ^d	0,64(13)	0,218(44)	—	
¹⁰³ Rh	803,1(2)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,70	M1	1,85(16)	0,174(15)	—	Harmatz (1979)
¹⁰³ Rh	1277,0(2)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,75	- 0,62(30) ^e	0,81(9)	0,87(10)	1,3(9)	Harmatz (1979)
¹¹³ In	1177(1)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	1	+ 0,5(2)	9,1(8)	0,086(8)	0,10(6)	Tuttle et al (1976)
¹¹³ In	1510(1)	$\frac{3}{2}^-$	$\frac{3}{2}^-$	0,935	- 0,5 ⁽⁺¹⁾ ₍₋₂₎	6,4(9)	0,071(10)	0,11 ⁽⁺²⁾ ₍₋₃₎	Tuttle et al (1976)
¹¹⁵ In	1077,7(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,81 ⁱ	(E2)	0,159(24)	1,61(24)	1,23(7)	Tuttle et al (1976)
¹¹⁵ In	1290,59(3)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,98 ^j	(E2)	1,31(11)	0,66(6)	0,55(4)	Tuttle et al (1976)
¹¹⁵ In	1448,78(3)	$\frac{3}{2}^-$	$\frac{3}{2}^-$	0,86	- 8 ^f	0,90(11)	0,50(6)	0,52(20)	Tuttle et al (1976)
¹¹⁵ In	1486,1(1)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,787	- 0,8 ^f	0,63(9)	0,63(9)	0,4(3)	Tuttle et al (1976)
¹¹⁵ In	1497,2(4)	($\frac{1}{2}^+$)	($\frac{1}{2}^+$)	< 1	(E2)	1,33(16)	< 0,30(4)	—	
¹¹⁵ In	1607,8(15)	($\frac{1}{2}^+$)	($\frac{1}{2}^+$)	≪ 1	(E2)	1,54(24)	≤ 0,26(4)	—	
¹¹⁶ Sn	1293,54(2)	2 ⁺	0 ⁺	1	E2	3,58(37)	0,53(6)	0,522(14)	Carlson et al (1975)
¹¹⁸ Sn	1229,64(4)	2 ⁺	0 ⁺	1	E2	2,75(28)	0,69(7)	0,67(2)	Carlson et al (1976)
¹²⁰ Sn	1171,6(2)	2 ⁺	0 ⁺	1	E2	1,83(16)	1,04(9)	0,91(2)	Kocher (1976)
¹²¹ Sb	1023,5(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	1	|0,57|^g	3,69(34)	0,228(21)	0,20(7) ^h	Tamura et al (1979)
¹²¹ Sb	1105,5(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,4	—	0,47(4)	0,42(4)	—	
¹²¹ Sb	1142,5(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	0,6	(E2)	0,85(8)	0,449(40)	0,41(8) ^h	Booth et al (1973)
¹²¹ Sb	1384,0(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	1	|0,45|^g	4,7(5)	0,092(10)	0,088(14) ^h	Booth et al (1973)
¹²³ Sb	1029,5(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	1	|0,57|^g	2,96(27)	0,272(25)	0,26(4) ^h	Booth et al (1973)
¹²³ Sb	1086,5(10)	$\frac{1}{2}^-$	$\frac{1}{2}^-$	1	|δ| > 1,26 ^g	1,06(9)	0,67(6)	0,72(15) ^h	Booth et al (1973)

† Références pour les colonnes 3, 4, 5, 6 et 9 de chaque ligne, sauf indication appelée au bas de ce tableau. Pour les autres données se reporter au texte.

Remarque. Pour calculer δ^2 quand nous ne disposons que de $B(E2)$, pour un mélange (E2) + (M1), nous déduisons $g\Gamma_0(E2) \propto B(E2)E_F^2$; en admettant $W(\theta) = 1$ et connaissant Γ_0/Γ , notre détermination de u donne une première approximation de $g\Gamma_0$ d'où une valeur de $\delta^2 = (g\Gamma_0(E2))/(g\Gamma_0 - g\Gamma_0(E2))$ qui permet d'améliorer $W(\theta)$ et $g\Gamma_0$ de proche en proche.

^a Swann (1971); ^b Robinson et al (1967); ^c $W(\theta) = 0,99$ calculé d'après la formule de Celliers et al (1977); ^d Abbondanno et al (1978); ^e Sayer et al (1972); ^f Tuttle et al (1976); ^g d'après $B(E2)$ de Barnes et al (1966); ^h calculé d'après Booth et al (1973); ⁱ Williams et al (1975); ^j Dietrich et al (1970).

REF. W.R. Dodge, R.G. Leicht, E. Hayward, E. Wolyneć
Phys. Rev. C24, 1952 (1981)

ELEM. SYM.	A	Z
Co	59	27
REF. NO.		
81 Do 2		hg

METHOD			SOURCE		DETECTOR		ANGLE
REACTION	RESULT	EXCITATION ENERGY	TYPE	RANGE	TYPE	RANGE	
E, P	ABX	7-100	D	16-100	MAG-D		DST
E, A	ABX	7-100	D	16-100	MAG-D		DST

The (e,p) and (e,α) cross sections for ⁵⁶Fe, ⁵⁹Co, and ⁶⁴Zn have been measured in the electron energy range 16–100 MeV. They have been analyzed using the distorted-wave Born approximation E1 and E2 virtual photon spectra. The E1 and E2 components in the proton and α channels have been obtained.

VIRT PHOTON ANAL

NUCLEAR REACTIONS ⁵⁶Fe(e,p), ⁵⁶Fe(e,α), ⁵⁹Co(e,p), ⁵⁹Co(e,α), ⁶⁴Zn(e,p), and ⁶⁴Zn(e,α); measured $\sigma(E_0, E_x, 34^\circ)$, $\sigma(E_0, E_x, 48^\circ)$, $\sigma(E_0, E_x, 62^\circ)$, $\sigma(E_0, E_x, 90^\circ)$, $\sigma(E_0, E_x, 118^\circ)$, $\sigma(E_0, E_x, 132^\circ)$; obtained $\sigma(e,p)$, $\sigma(e,\alpha)$; deduced $\sigma_{\gamma,p}^{E1}(E)$, $\sigma_{\gamma,p}^{E2}(E)$, $\sigma_{\gamma,\alpha}^{E1}(E)$, $\sigma_{\gamma,\alpha}^{E2}(E)$.

¹³Y. -W., Lui, P. Bogucki, J. D. Bronson, U. Garg, C. M. Rozsa, and D. H. Youngblood, Phys. Lett. 93B, 31 (1980).

¹⁴S. Costa, F. Ferrero, S. Ferroni, C. Molino and R. Malvano, Phys. Lett. 11, 324 (1964). 64 Co 2

TABLE III. Percentage of the E2 sum when only points up to 50 MeV ($E_0=50$ MeV) and when all measured points ($E_0=100$ MeV) are considered in the analysis. The bremsstrahlung cross section used is DBM. E2 sum: $0.22Z^2A^{-1/3}$ μb/MeV.

Nucleus	Reaction	Without size effect		With size effect	
		$E_0=50$ MeV	$E_0=100$ MeV	$E_0=50$ MeV	$E_0=100$ MeV
⁵⁶ Fe	(e,α)	9± 3	3 ± 1	11± 3	7± 1
	(e,p)	47±30	8±11	61±32	37±15
⁵⁹ Co	(e,α)	7± 2	4 ± 1	8± 2	5± 1
	(e,p)	32±22	4± 8	48±24	28±11
⁶⁴ Zn	(e,α)	26± 6	12± 2	32± 6	25± 3
	(e,p)	29±43	26±15	56±46	77±21

TABLE IV. Percentage of the E1 and E2 sums in the α and proton channels. E1 sum: $60NZ/A$ MeV mb. E2 sum: $0.22Z^2A^{-1/3}$ μb/MeV. Integrals to 100 MeV.

Nucleus	Reaction	E1		E2	
		Schiff	DMB	Schiff	DBM
⁵⁶ Fe	(e,α)	5± 1	6± 1	10± 1	7± 1
	(e,p)	67±20	82±19	82±14	37±15
	(e,α)+(e,p)	72±20	88±19	92±14	44±15
⁵⁹ Co	(e,α)	5± 1	7± 1	8± 1	5± 1
	(e,p)	52±10	67±12	63±10	28±11
	(e,α)+(e,p)	57±10	74±12	71±10	33±11
⁶⁴ Zn	(e,α)	16± 4	18± 4	33± 3	25± 3
	(e,p)	129±28	154±30	137±30	77±21
	(e,α)+(e,p)	145±28	172±30	170±20	102±21

OVER

TABLE VI. $E1$ strength integrated up to 30 MeV.

Nucleus	α	$\int_0^{30} \sigma_{\gamma,x}(E) dE$ (MeV mb)		Total	Fraction of $E1$ sum
		p	n		
^{56}Fe	18 ± 3	256 ± 26	735^a	1009	1.21
^{59}Co	15 ± 2	211 ± 22	884^b	1110	1.26
^{64}Zn	66 ± 14	545 ± 75	616^b	1227	1.28

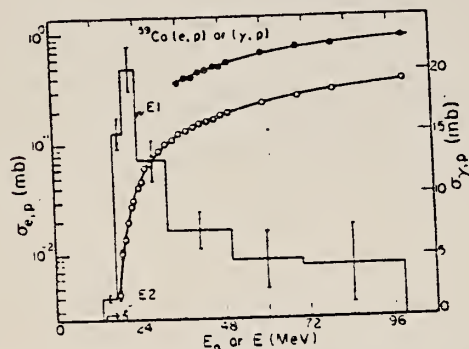
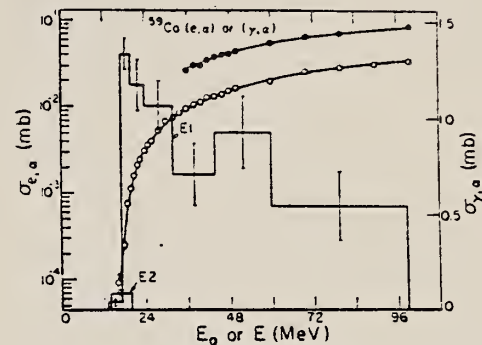
^aReference 13.^bReference 14.FIG. 4. The $\sigma_{e,p}(E_0)$ for ^{56}Co . See caption of Fig. 3.FIG. 7. The $\sigma_{e,a}(E_0)$ for ^{59}Co . See caption of Fig. 3.

FIG. 3. The measured $\sigma_{e,p}(E_0)$ for ^{56}Fe as a function of total incident electron energy E_0 (open circles). The full circles represent the yield $Y_{e,p}(E_0)$ obtained when a 0.217 g/cm^2 tantalum foil was placed in the electron beam ahead of the target. The smooth curves are the best fits to the data and were obtained by combining the histograms representing the $E1$ and $E2$ (γ, p) cross sections (right-hand scale) in Eqs. (1) and (2) with the $E1$ and $E2$ DWBA virtual photon spectra and by making use of the DBM bremsstrahlung cross section. The size effect correction described in the text has been applied to the virtual photon spectra.

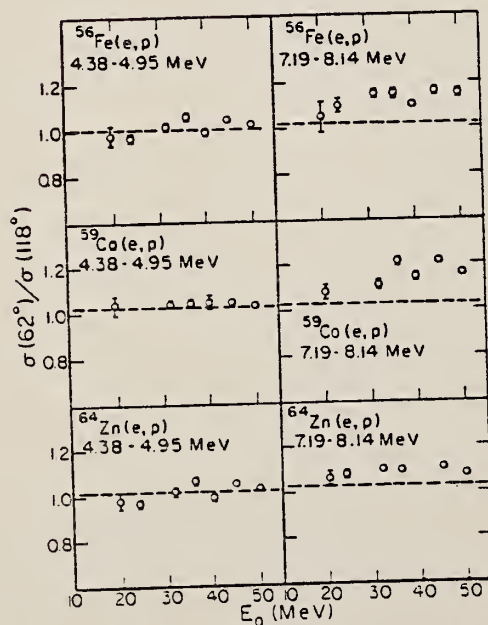


FIG. 9. The ratios of the number of protons observed in the indicated energy bite ΔT_p at 62° to the same number observed at 118° , $\sigma(62^\circ)/\sigma(118^\circ)$, as a function of incident electron energy.

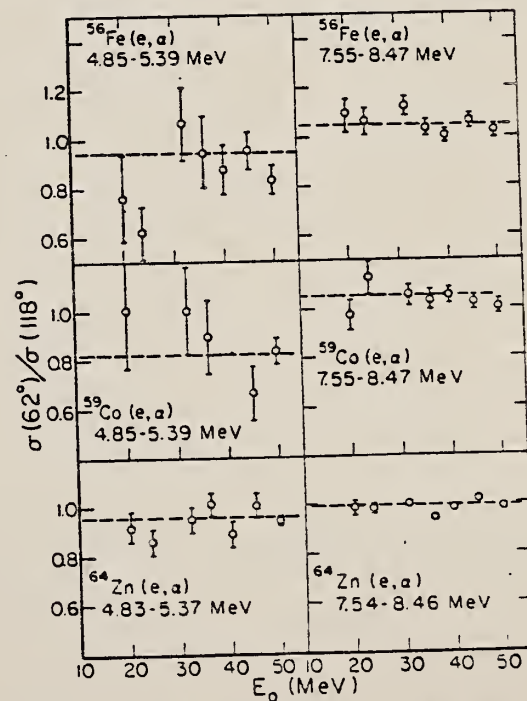


FIG. 10. The ratios of the number of α particles observed in the indicated energy bite ΔT_a at 62° to the same number observed at 118° , $\sigma(62^\circ)/\sigma(118^\circ)$, as a function of incident electron energy.

Co
A=60

Co
A=60

Co
A=60

REF. O. A. Wasson, M. R. Bhat, R. E. Chrien, M. A. Lone, and M. Beer
Phys. Rev. Letters 17, 1220 (1966)

ELEM. SYM.	A	Z
Co	60	27
REF. NO.		EGF
66 Wa 2		

METHOD

REACTION	RESULT	EXCITATION ENERGY	SOURCE		DETECTOR		ANGLE
			TYPE	RANGE	TYPE	RANGE	
N,G	RLX	7	D	0	SCD-D	5-8	45
		(7.49)					

$\sigma_{\text{g.s.}}$ = Ground-state capture γ 's for 3-500 eV neutrons.

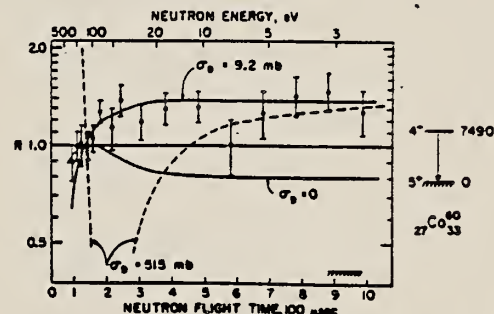


FIG. 2. The energy variation of $R \propto \sigma_{\text{g.s.}}/\sigma_{\text{tot}}$ for the ground-state transition. The curve $\sigma_D = 0$ would be the expected variation after correction for the presence of the 3^- bound state, with no interference assumed between the resonance and direct reaction amplitudes. The curves $\sigma_D = 9.2$ mb and $\sigma_D = 515$ mb result from constructive and destructive interference below the 132-eV resonance.

DEFINITIONS OF ABBREVIATIONS AND SYMBOLS

Note: In this list definitions are given for various photoneutron reactions in which the following symbols are used: N, NL, nN, SN and XN. Corresponding definitions apply for reactions involving other nuclear particles where the symbols N (neutron) is replaced by, e.g. P, D, T, HE, A etc. Where unknown reactions result in the production of a specific radionuclide, the chemical symbol and mass number is listed as the reaction product, e.g. a G,NA22 reaction in ⁵⁹Co.

A	alpha particle		response function. Contrast with D = discrete.
ANAL	analysis		
ABI	absolute integrated cross-section data	CCH	cloud chamber
		CF	compared with
ABX	absolute cross-section data	CHRGD	charged
ABY	absolute yield data. Often means cross-section per equivalent quantum is listed.	CMPT	Compton
		COIN COINC	coincidence, coincide
ACT	measurement of induced radio-activity of the target	COH	coherent
ASM	asymmetric, asymmetry	CK	Cerenkov
AVG	average	D	deuteron or discrete. When discrete, it is used to describe a photon source or a detector response function. Contrast with C = continuous.
BBL	bubble chamber		
BEL B(EL)	reduced electric radiative transition probability	DLTE	energy loss
BF3	BF ₃ neutron counter with moderator e.g., Halpern detector, long counter	DLTQ	momentum transfer
		DST	distribution
BML	reduced magnetic radiative transition probability, B(ML)	DT BAL	detailed balance
BREAKS	levels located by "breaks" in the yield curve	E	electron
		E/	inelastically scattered electron
BRKUP	breakup	E+	positron
BRMS	bremsstrahlung		
BTW	between	EDST	energy distribution or spectrum
C	continuous. Used to describe a photon source or a detector	E/N	used only to indicate a coincidence experiment as in (E,E/N).

N stands for any outgoing particle measured in coincidence with an inelastically scattered electron. Distinguish from eg., (E,N) which is used to represent an electron induced reaction when only the outgoing particle N is detected.

EMU emulsions (photographic plates)

EXCIT excited

F fission

FMF form factor

FM-1 inverse femtometers

FRAG fragment

G photon

G/ inelastically scattered photon

G-WIDTH gamma-ray transition width

HAD hadrons, hadron production

HE ^3He particle
He3

INT interaction, integral, intensity

INC includes

ION ionization chamber

ISOB isobaric

ISM isomer

J multiplicity of particle defined by following symbol e.g. (G,PJN) with remark $J = 2,3,5,7$

JPI spin and parity of a nuclear state
J-PI

K second multiplicity index, e.g. (G,JPKN) with both J & K positive integers greater than 1

KE kinetic energy

L may be an integer or zero that always follows a reaction product symbol. This is used to indicate transitions to specific states in the residual nuclide. When the letter is used as in (G,NL) the cross section given is that for the sum of transitions to two or more specific final states.

LFT excited state lifetime

LIM limit

LV,LVS level, levels

LQD liquid

MAG magnetic spectrometer

MEAS measurement(s)

MGC magnetic Compton spectrometer

MGP magnetic pair spectrometer

MOD moderated neutron detector not employing a BF_3 counter, e.g. rhodium foil, Szilard-Chalmers reaction, ^3He , ^6Li reactions, GD loaded liquid scintillator, etc.

MSP mass spectrometer

MULT multiple, multipole, multiplicity

MU-T used only in combination with G to indicate a total photon absorption cross section measurement, i.e. (G,MU-T)

N neutron (see also XN and SN). The notation (G,N) is used to indicate a reaction in which only a single neutron is emitted, i.e. the reaction that can, in many cases, be measured by observing the radioactive decay of the residual nuclide.

nN	where n is any integer. (G,nN) indicates the sum over all reaction cross sections in which n neutrons are emitted.	SN	sum of neutron producing reactions, $\sigma(\gamma, SN) = \sigma(\gamma, N) + \sigma(\gamma, NP) + \sigma(\gamma, 2N) + \sigma(\gamma, 3N) + \text{etc.}$
NAI	NaI(Tl) spectrometer	SPC	photon or particle energy spectrum
NEUT	neutron(s)	SPK	spark chamber
NOX	no cross-section data	SPL	spallation
P	proton (see also XP)	STAT	statistical
PART	particle(s)	SYM	symetric, symmetry
PHOT	photon(s)	T	triton
PI	pion, usually written as PI^+ , PI^- , PI^0 to indicate charge	TEL	counter telescope
POL	polarized or polarization	THR	threshold for reaction or threshold detector, e.g., $^{29}Si(n,p)^{29}Al$.
Q-SQUAR	momentum transfer squared (q^2)	TOF	time-of-flight detector
RCL	recoil	TRK	tracks of particles or fragments observed in solid materials (glass, mylar, etc.)
REL	relative	TRNS	transition
RLI	relative integrated cross-section data	UKN UNK	unknown
RLX	relative cross-section data	VIB	vibrational
RSP	reaction spectrometer	VIR PHOT	virtual photon(s)
RLY	relative yield data	XN	all neutrons, total neutron yield, $\sigma(\gamma, XN) = \sigma(\gamma, N) + 2\sigma(\gamma, 2N) + 3\sigma(\gamma, 3N) + \sigma(\gamma, NP) + \text{etc.}$
SCTD	scattered	XP	all protons, total proton yield $\sigma(\gamma, XP) = \sigma(\gamma, P) + \sigma(\gamma, NP) + 2\sigma(\gamma, 2P) + \text{etc.}$
SCD	semiconductor (solid state) detector	XX XXX	reaction products defined in REMARKS
SCI	scintillator detector other than NaI, e.g., CsI, KI, organic (liquid or solid), stilbene, He	YLD	yield
SEP	separation		
SEP ISOTP	separated isotope used		
SIG	SIGMA (cross section)		

4PI	a 4π geometry was used or a method like radioactivity or a total absorption measurement		products was determined. The polarized particle is indicated in REMARKS.
999	energy defined in REMARKS	* or @	symbols used to indicate that the units associated with the numerals on one or both sides of the symbol in a specific column are not MeV. The units are defined in REMARKS.
\$	indicates the measurement involved beams or targets that were either polarized or aligned, or that the polarization of the reaction		

U.S. DEPT. OF COMM. BIBLIOGRAPHIC DATA SHEET (See instructions)		1. PUBLICATION OR REPORT NO.	2. Performing Organ. Report No.	3. Publication Date
4. TITLE AND SUBTITLE Photonuclear Data-Abstract Sheets 1955-1982				
5. AUTHOR(S) E.G. Fuller and Henry Gerstenberg				
6. PERFORMING ORGANIZATION (If joint or other than NBS, see instructions) NATIONAL BUREAU OF STANDARDS DEPARTMENT OF COMMERCE WASHINGTON, D.C. 20234			7. Contract/Grant No.	8. Type of Report & Period Covered
9. SPONSORING ORGANIZATION NAME AND COMPLETE ADDRESS (Street, City, State, ZIP)				
10. SUPPLEMENTARY NOTES <input type="checkbox"/> Document describes a computer program; SF-185, FIPS Software Summary, is attached.				
11. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here) These abstract sheets cover most classes of experimental photonuclear data leading to information of the electromagnetic matrix element between the ground and excited states of a given nucleus. This fifteen volume work contains nearly 7200 abstract sheets and covers 89 chemical elements from hydrogen through americium. It represents a twenty-seven year history of the study of electromagnetic interactions. The sheets are ordered by target element, target isotope, and by an assigned bibliographic reference code. Information is given on the type of measurement, excitation energies studied, source type and energies, detector type, and angular ranges covered in the measurement. For a given reference, the relevant figures and tables are mounted on a separate sheet for each nuclide studied.				
12. KEY WORDS (Six to twelve entries; alphabetical order; capitalize only proper names; and separate key words by semicolons) data-abstract sheets, elements, experimental, isotopes, nuclear physics, photonuclear reactions				
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